# IMPACT OF STANDARDS ON HYDROCARBON REFRIGERANTS IN EUROPE

Market research report

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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## ABBREVIATIONS

- **AC**: Air conditioning
- **EAHP**: Exhaust air heat pump
- **EER**: Energy efficiency ratio
- **GHG**: Greenhouse gas
- **GWP**: Global warming potential
- **HC**: Hydrocarbon
- **HFC**: Hydrofluorocarbon
- **HFO**: Hydrofluoroolefin
- **HP**: Heat pump
- **HVAC&R**: Heating, ventilation, air conditioning & refrigeration
- **ISEER**: Indian seasonal energy efficiency ratio
- **LCC:** Life cycle cost
- **ODP**: Ozone depletion potential
- **RAC**: Residential air conditioning
- **RACHP**: Refrigeration, air conditioning, heat pump
- **ROI**: Return on investment
- **SAG**: Standards Action Group
- **SEER**: Seasonal energy efficiency ratio

# EXECUTIVE SUMMARY

For refrigeration, air conditioning and heat pump (RACHP) applications, hydrocarbons represent an energy efficient and low global warming alternative to hydrofluorocarbons (HFCs). Given the F-Gas Regulation (EU) No 517/2017 requires a reduction in HFCs of more than two thirds by 2030, the market for hydrocarbon-based equipment is expected to see a vibrant growth in coming years.

The report investigates the current use of hydrocarbon refrigerants and evaluates the impact of standards on the future adoption of equipment using these refrigerants. The report is structured into two main parts. The first n

The review of existing safety standards demonstrates that the primary barriers to flammable refrigerants in safety standards are mainly related to refrigerant charge size limits, which limit the ability of systems to provide the desired cooling capacity.

Several risk mitigation measures are explored to address the identified barriers to flammable refrigerants and increase the allowed refrigerant charge size. The review has determined that the following risk-mitigation measures are of use:

- Improved system tightness
- Systems with integral airflow
- Charge leak test method
- Housing design
- Sources of ignition test method

Efforts to review the current charge size limits for flammable refrigerants are underway within several European and international standards relevant to the refrigeration, air conditioning and heat pump (RACHP) sector. Nevertheless the process is lengthy and the timelines for review are unclear in most cases. The development of requirements is in general much more advanced for A2L refrigerants than for A3 refrigerants (hydrocarbons).

While the discussions are underway on several issues concerning A3 refrigerants within group standards EN 378 and ISO 5149 (e.g. improved charge limit for hydrocarbons below ground), there is currently no clear timeline for publication of revised standards.

The on-going revision of product standards IEC 60335-2-89 (commercial refrigeration) and IEC 60335-2-40 (air conditioning and heat pumps) relates to the charge size limitations of A3 refrigerants. In case of IEC 60335-2-40, a proposal to address the charge size of A3 and mitigation measures is currently at committee draft stage and a revised standard is expected in 2019-2022 timeframe. The revision of charge size limits for hydrocarbons in commercial refrigeration is progressing at a faster pace and a revised standard that could increase the charge limit for propane in commercial refrigeration to 500g (from today's 150g) is expected to be published in early 2019 unless unexpected delays in the process.

The research on the current market for hydrocarbon-based equipment revealed that the main driver for adoption of this technology is the low environmental impact (direct & indirect emissions), followed by compliance with current and future legislation.  As expected, safety concerns and current limitations on charge sizes were ranked as the most important barriers to wider uptake of hydrocarbon refrigerants.

As for the current market size of hydrocarbon-based equipment, the analysis unveiled that there is only a limited number of producers manufacturing significant share of products using these natural refrigerants. The situation appears different from the HFCs industry, whereby a considerable number of multinationals still manufacture an extensive share of products based on synthetic refrigerants.

Out of the three applications considered (heat pumps, commercial refrigeration and air conditioning), the number of hydrocarbon-based display cabinets in supermarkets is around 2.5 million globally. According to the data collected from equipment manufacturers, there are more than 200,000 heat pumps and a similar number of portable ACs using hydrocarbons in Europe. Nevertheless, propane is expected to see a robust growth in the short-term especially for portable AC units. The numerous case studies presented show how hydrocarbons can already be a safe reality, describing their use in different contexts. On the other hand, it is a further indicator of how developed this technology already is in wide array of applications.

Over half of respondents indicated they already work with hydrocarbons to some extent. Out of those that do not yet offer or use products with hydrocarbons, over 50% plans to start in the future, while about 30% is undecided. More than two thirds of those that will start working with hydrocarbons plan to do that by 2020. This finding demonstrates that the industry anticipates the prohibitions and growing HFC prices under the F-Gas Regulation, but also expects the industry standards to allow for this transition within 2 years.

Investigating the impact of current standards on the availability and uptake of hydrocarbon-based equipment, it emerged that current charges set in standards both limit and obstruct the development of hydrocarbon technology. A large number of companies admitted that higher charges would facilitate an expansion of their market; others are simply not yet in the market because their products would require higher charges than the ones currently allowed.

In case of commercial refrigeration, more than 62% of survey respondents indicated they manufacture equipment with multiple refrigeration circuits as a way to overcome the charge restriction barrier in larger applications. Allowing higher hydrocarbon refrigerant charges in a single refrigeration circuit under industry standards could therefore have a profound impact on the cost and availability of these units.

Alongside the uniform and meaningful change in standards, further elements could play a pivotal role in ensuring wider uptake of hydrocarbon-based system. Awareness raising and information sharing activities are crucial to explain the safety features and how to minimise the flammability risk. In addition, training and certification programmes allowing manufacturers, installers and technicians to handle these innovative technologies with all the due precautions, are an essential prerequisite for a wider use of hydrocarbons.

Furthermore, in term of mitigation measures, additional lab tests and experiments on various aspects - system tightness, systems with integral airflow, charge leaks, housing design, ignition sources - are expected to lead to crucial outcomes contributing to the development of hydrocarbon-based RACHP applications.

The market research and the related findings will serve as a basis for ongoing and future project phases under LIFE FRONT, informing activities on project safety design, laboratory testing and engagement with standardisation development processes.

# CHAPTER 1: INTRODUCTION

## 1.1 About LIFE FRONT project

LIFE FRONT is a demonstration project funded under the LIFE programme of the European Union (Climate Change Mitigation 2016 priority area). It aims to remove the barriers posed by standards for flammable refrigerants in refrigeration, air conditioning and heat pump (RACHP) applications. In doing so, the project serves also to increase the availability of suitable alternatives in those areas, by improving system design to address flammability risks to encouraging the use of climate-friendly alternatives to fluorinated gases, in particular hydrocarbons.

The project started its activities in June 2017 and involves six partners from four European countries, namely Austria, Belgium, Germany and Sweden.

To meet its objectives, LIFE FRONT serves to:

- Support the EU and the international standardisation process for flammable refrigerants;
- Reduce safety risks from improved system design for air conditioning, refrigeration and heat pump applications using flammable refrigerants;
- Engage in technology capacity building for EU equipment manufacturers;
- Remove non-technological knowledge barriers, through general awareness-raising and stakeholder dialogue;
- Improve Europe's competitiveness for RACHP equipment using non-fluorinated based alternative refrigerants;
- Support an effective and timely achievement of the EU 2030 climate targets, through the F-Gas Regulation, Ecodesign Directive, Renewable Energies Directive and other legislative instruments for the reduction of fluorinated gases.

In brief, the project impacts the EU innovation policy, consolidating the knowledge base for developing, assessing and implementing climate policy.

For promoting the use of flammable refrigerants in RACHP systems, current safety standards need to be adopted to foster the use of these refrigerants in a safe way. Hence a risk assessment for the use of flammable refrigerants and the selection of reasonable risk parameters (including the frequency of leaks, mass flow rates, etc.) need to be considered as input parameters for safety standards, determining among others the allowable charge sizes and system design parameters.

For many of the RACHP safety standards the concepts currently used lack methodological robustness.

The replacement of hydrofluorocarbons (HFCs) with low GWP environmentally friendly refrigerants (particularly hydrocarbons - HCs) is key in the reduction of greenhouse gas (GHG) emissions from RACHP equipment. Due to their favourable thermodynamic properties hydrocarbons are an important alternative for RACHP appliances. Although these refrigerants are promising to replace conventional HFCs, they are flammable. It is thus essential to understand the details of their ignition risk. Major contributing factors are the likelihood/frequency of a leak, the amount and persistence of the flammable volume and the occurrence of ignition sources.

The project is composed of various actions targeting specific aspects:

- *Literature review and market study*. To counter the lack of one comprehensive overview of standards for non-fluorinated flammable refrigerants at the EU and international level, a thorough literature review with a mapping of all relevant standards was carried out. Parts of it are exploited by the present market study investigating the impact of current (restrictive) standards on the European HVAC&R industry. The report maps the available technology solutions and product groups using hydrocarbon refrigerants, their expected future availability, and the impact of standards on such market development. These activities are to be completed within the first year of the project, to serve as a basis for following deliverables.

- *Leak analysis, gas concentration and consequences*. Critical to the risk analysis of flammable refrigerants is the determination of leak size and subsequent mass flow of refrigerant release. Anecdotal information and limited published data indicate that the leak scenario used in current standards[1] is extremely rare. Therefore, technical specifications based on these assumptions are disproportionate to the likelihood of a severe hazard occurring. In this regard, the activities of the project aim to collect extensive field data to analyse leaks in existing RACHP systems, establishing a leakage database by carrying out measurement of leaks identified during visits of manufacturers' service departments or contracted service companies. Following activities include studies on the identification of leak mass flow rates (designing leak hole fittings to simulate leak holes at different locations in the system) and studies on concentration development (to develop a leak simulation database).

- *Improved product safety design and risk assessment*. Building on the above-mentioned activities, LIFE FRONT aims to study the design and construction of RACHP equipment in order to minimise flammability risk. Sometimes, the implementation of mitigation measures can be conflicting in terms of their impact on risk reduction, while the practicality of passive and active risk reducing measures needs to be applied in order to demonstrate their applicability. The overall effectiveness of these measures and associated proposed refrigerant charge size limits must be validated through quantitative risk assessment.

- *Standardisation action and capacity building*. LIFE FRONT aims to translate the outputs of previously-described activities into concrete standardisation deliverables. Firstly, the draft requirement for flammable refrigerant standards will be issued and translated into valuable input to the ongoing standardisation processes. Secondly, project partners participate in standardisation activities and strategic discussions, targeting the entire standards development process. Lastly, a Standards Action Group (SAG) has been created to gather around 50 relevant stakeholders (manufacturers, policymakers, trade associations, etc.) to establish consistency between regulatory and standardisation developments.

- *Communication and dissemination*. To facilitate information exchange among all project partners, institutions, relevant stakeholders and a wider public, activities and outcomes of the project are communicated through various channels, including online (websites, social media, newsletter), print material (report, flyers), mass media (articles, press releases) and events (webinars, presentations). In addition, a "FRONT" Communication Centre was developed on the project website (http://lifefront.eu/) to serve as a space for discussion for the members of SAG, to exchange information and share work documents.

[1] Current standards adopt the "worst case" scenario assumptions, i.e. that the entire charge is being released in a short period of time.

### 1.1.1 Report structure

The following section 1.2 describes the methodology used in preparing this report and how data was collected, whereas in the section 1.3 it provides a general introduction to hydrocarbons, their properties and key applications.

Chapter 2 gives an introduction to standards and the standardisation process, both from a general perspective and focusing on flammable refrigerants in particular. The report offers a brief overview of the main standardisation bodies both at the EU and international level. Contextually we highlight why a revision of current standards for the use of flammable refrigerants in RACHP systems is necessary.

The general market trends and the most relevant case studies for hydrocarbon-based technology in RACHP applications are described in Chapter 3.

The following Chapter 4 discusses the market potential for hydrocarbons in the HVAC&R sector.

Chapter 5 concludes by casting a light on the main results achieved in this report and the most pressing actions to be fulfilled for a wider uptake of hydrocarbons in RACHP systems.

## 1.2 Methodology

Market development company shecco, partner of the LIFE FRONT project, undertook research to analyse the availability of hydrocarbon-based equipment and the impact of standards. The data and the information used for this report were collected in several different ways, in order to reflect the commercial dimension of the addressed barriers from standards as accurately as possible.

### 1.2.1 Desk research

As a first step, shecco conducted an extensive literature review of standards, existing case studies and market trends from available internal and external online and print sources. Consequently, a thorough review of the most interesting information was completed, to select those that fit the purposes of the present report in the most appropriate way. The desk research served as a basis for the next steps in the research process.

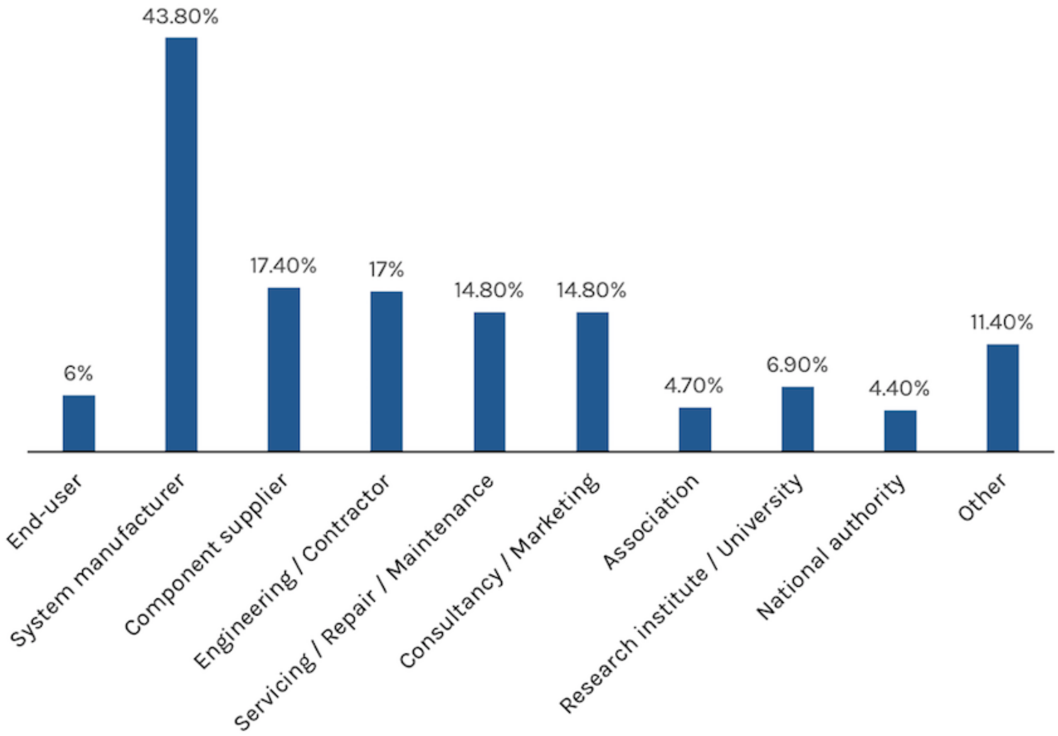
### 1.2.2 Industry survey

In order to reflect industry views, shecco launched an online survey that collected responses from over 450 industry representatives[2]. The questionnaire was distributed to a wide audience of industry experts that provide or use RACHP services and products using both traditional HFC refrigerants as well as natural cooling fluids.

The survey asked respondents to identify the type of organisation they represent or are active in. System manufacturers were by far the most represented (43.4%).

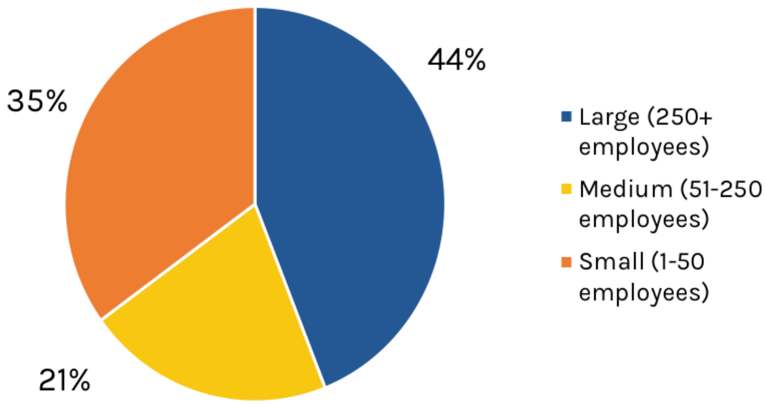
[2] Between March and May 2018, 461 individual responses were collected, of which 175 complete and 286 partial.

Image 1.2.1: Organisation type of survey respondents



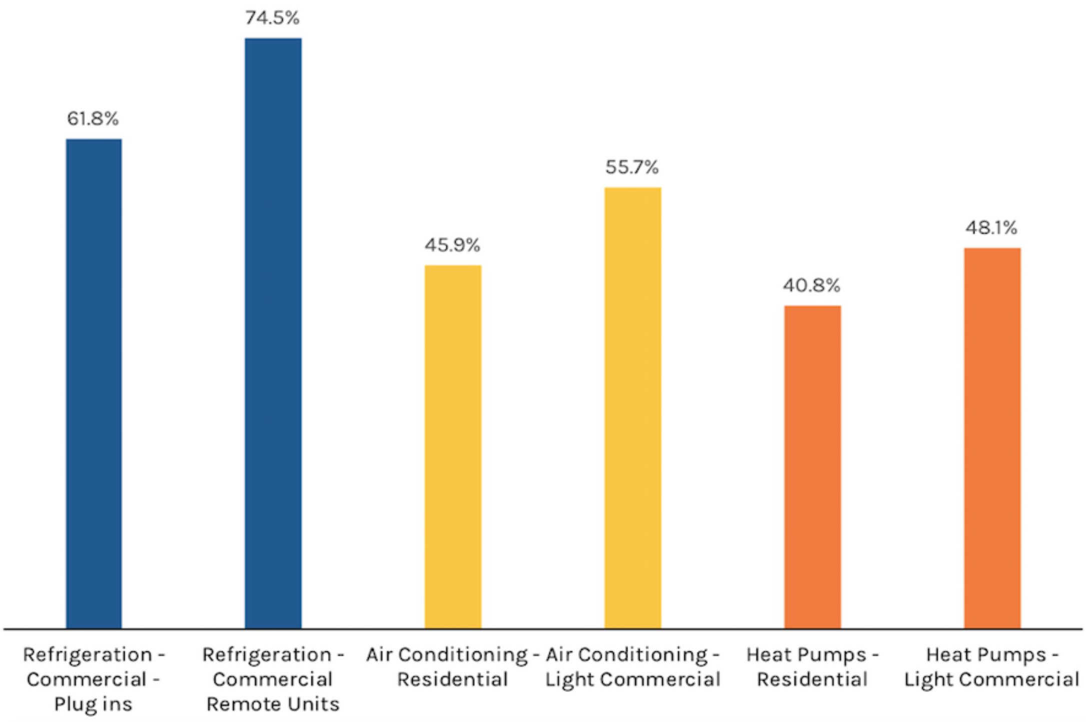

Approximately 44% of the respondents were representatives of large companies (more than 250 employees). 35% of the respondents that answered the questionnaire work in small businesses that employ 1 - 50 people. The remaining respondents (21%) typically worked at medium-sized companies (50-249 employees).

Image 1.2.2: Size of companies of survey respondents (number of employees)




To better understand the division of applications that are represented in the responses, the survey asked respondents to identify the sector they are active in. Commercial refrigeration for plug-in and remote units were the most represented sectors with remote units having the highest proportion of positive responses with 74%. Less respondents declared to work with air conditioning (42% for residential and 51% for light commercial use) and heat pumps (39% for residential and 45% for light commercial use).

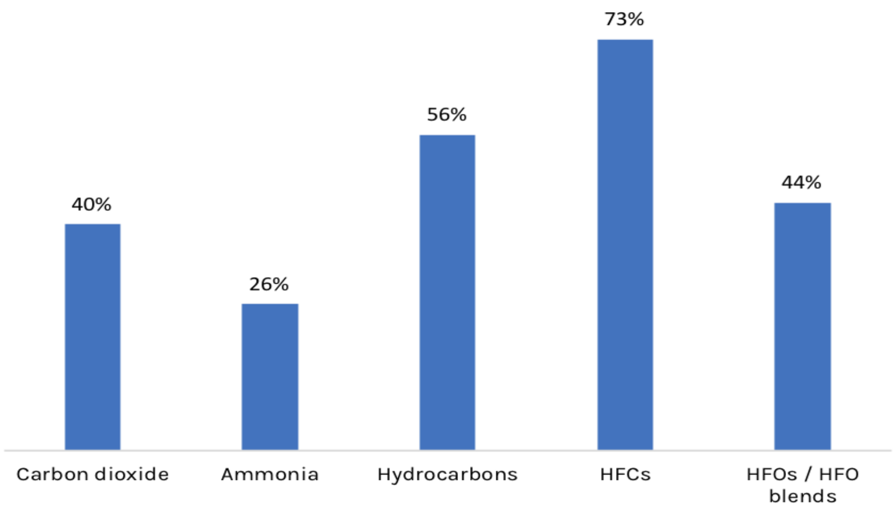
Image 1.2.3: HVAC&R sectors that survey respondents are active in




The survey was open to respondents from all over the world, consequently, the location of respondents is fragmented. Almost half (49%) of respondents indicated they are located in the EU (Belgium, France, Germany, Italy, the Netherlands, Spain, Sweden and the UK): high numbers were collected for Germany (10%) and the UK (8%). Besides Europe, Australia (9%) and the U.S. (13%) were well represented. The remaining 29% of respondents come from other countries with none of these countries presenting more than 2%.

The respondents had the possibility to indicate whether they use natural refrigerants, hydrofluorocarbons (HFCs) or new low-GWP HFC refrigerants (HFOs) in their main area of activity. Although almost 70% of respondents use HFCs, 57% also claim to use hydrocarbons. Other natural refrigerants are used by a smaller number of respondents.

Image 1.2.4: Refrigerant used by survey respondents



### 1.2.3 Data collection and interviews

In addition to the industry online survey, shecco collected data concerning the current use of hydrocarbon-based equipment among industry project partners, SAG members and other relevant external contacts. In total, the data sheet organised for each of the analysed sectors, was sent to approximately 100 contacts. It aimed to collect data for the number of units produced and their capacity (in kW).

Additional telephone interviews were arranged for further clarifications.

Besides this, the "FRONT" Communication Centre (the internal forum for project consortium and SAG members, hosted on the project website) was used to collect additional qualitative feedback from SAG members.

### 1.2.4 Other: Events & networking

When possible, additional useful information were collected when attending events or in networking occasions with partners and external stakeholders. Interviews and surveys were conducted at Mostra Convegno and Venditalia trade shows in Milan (Italy): at these events some of the latest developments in technology were showcased as well. Insights were gained attending industry-leading conferences such as ATMOsphere (organised by shecco) France 2018 in Paris (France) and Gustav Lorentzen 2018 in Valencia (Spain). Further networking with policymakers and trade associations took place during the 40$^{th}$ OEWG Meeting in Vienna and two other high-level meetings on the EU's F-Gas Regulation in Brussels and Rome.

## 1.3 About hydrocarbons and key applications

With zero ozone depleting potential (ODP) and an ultra-low global warming impact (GWP), hydrocarbon refrigerants do not form any by-products or decomposition products in the atmosphere.

Hydrocarbon refrigerants are fully compatible with almost all lubricants commonly used in refrigeration and air conditioning systems. One major exception to this rule is lubricants containing silicon and silicate (additives which are commonly used as antifoaming agents).

The three most widespread hydrocarbons are isobutane, propane and propylene:

- Isobutane (R600a): It is a low-pressure refrigerant with operating pressures and volumetric refrigeration capacity less than half that of R134a[3] but with good efficiency. It is used extensively for small refrigeration systems such as domestic refrigeration and small commercial systems.
- Propane (R290): It has thermodynamic properties like R22[4], although slightly lower pressure and capacity. Due to its excellent thermophysical properties the efficiency is good under most conditions, including in high ambient climates, as well as having low discharge temperatures. It is the most frequently used HC refrigerant in air conditioning/heat pump applications.

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[3] R134a is a common HFC refrigerant used in a wide range of RACHP applications. Given its contribution to climate change (GWP 1430), recently its use has been subject to restrictions .

[4] Following the phase out of CFCs, R22 became probably the most common HCFC refrigerant in many applications. The use of HCFCs for RACHP equipment in the EU is illegal since January 2015; broken HCFC-based equipment must be replaced with equipment that uses alternative refrigerants.

- Propylene (R1270): It is an unsaturated HC with distinctive odour and a vapour pressure and volumetric refrigerating capacity almost identical to R22. Due to its excellent thermophysical properties the efficiency is good under most conditions, including in high ambient climates, as well as having low discharge temperatures.

The flammable chemical properties of hydrocarbons (for which they are included in the A3 safety group[5]) are managed in different applications. The safety of hydrocarbons (as well as other refrigerants) is governed by regulations that impose measures on their application and at a second level, international, regional and national RACHP safety standards and codes. Many of these, however, restrict the safe use of hydrocarbons and need to be updated to take into account the technological progress that has been made.

In order to combust hydrocarbons, three conditions (the "fire triangle") have to be met[6]:

1. Ignition source of sufficient energy to start the combustion;
2. Oxygen that air contains must be within the correct fuel/air mixture for combustion to occur;
3. Hydrocarbon and air mixture ratio must be within the flammability ranges of lower and upper flammability limit.

For example, R290 combusts when the ratio of R290 and air is between 2-10% of R290 and 90-98% of air, in the presence of a sufficiently strong ignition source.

The following Table 1.3.1 compares the properties and safety classification for R290, R600a and R1270.

Table 1.3.1: Key characteristics of propane, isobutane and propylene

| Refrigerants | Propane | Isobutane | Propylene |
|---|---|---|---|
| Refrigerants number | R290 | R600a | R1270 |
| Chemical formula | $C_3H_8$ | $C_4H_{10}$ | $C_3H_6$ |
| GWP (100 years) | 3.3 | 4 | 1.8 |

[5] According to standard EN 378, in terms of safety group classification for each refrigerant the capital letter corresponds to toxicity and the digit to flammability.
Refrigerants are divided into two groups according to toxicity:
- Class A signifies refrigerants for which toxicity has not been identified at concentrations less than or equal to 400 ppm;
- Class B signifies refrigerants for which there is evidence of toxicity at concentrations below 400 ppm.

Refrigerants are divided into three groups according to flammability:
- Class 1 indicates refrigerants that do not show flame propagation when tested in air at 21°C and 101 kPa;
- Class 2 indicates refrigerants having a lower flammability limit of more than 0.10 kg/m$^3$ at 21°C and 101 kPa and a heat of combustion of less than 19 kJ/kg;
- Class 3 indicates refrigerants that are highly flammable as defined by a lower flammability limit of less than or equal to 0.10 kg/m$^3$ at 21°C and 101 kPa or a heat of combustion greater than or equal to 19 kJ/kg.

CEN (2016). *EN 378-1: 2016 - Refrigerating systems and heat pumps - Safety and environmental requirements - Part 1: Basic requirements, definitions, classification and selection criteria.* CEN, Brussels, Belgium.

[6] Koh J.H., Zakaria Z., Veerasamy D. (2017). *Hydrocarbons as Refrigerants - A Review.* ASEAN Journal on Science and Technology for Development, 34(1), 35-50.

| | | | |
|---|---|---|---|
| ODP | 0 | 0 | 0 |
| Normal boiling points (°C) | -42.1 | -11.8 | -48 |
| Critical temperature (°C) | 96.7 | 134.7 | 91 |
| Critical pressure (bar) | 42.5 | 36.48 | 46.1 |
| Safety group | A3 | A3 | A3 |
| Molecular weight (g/mol) | 44.1 | 42.08 | 42.08 |

### 1.3.1 Key applications

Typical applications for hydrocarbons include self-contained residential and light commercial equipment, such as domestic refrigerators and freezers, stand-alone light commercial refrigerators, bottle coolers, ice cream freezers, beverage dispensers and beer coolers. As well as air-conditioners, heat pumps and dehumidifiers.

In addition, hydrocarbons are used in supermarket refrigeration in combination with a secondary fluid or at the high temperature stage in a cascade $CO_2$ system. In Europe practically all new domestic fridges utilise R600a as a refrigerant.

In larger applications, such as commercial air conditioning and process cooling hydrocarbons can be used in chillers.

# CHAPTER 2: STANDARDS

## 2.1 Background on standards

A standard provides rules, guidelines or characteristics for activities or their results, for common and repeated use. Standards are created through consensus by bringing together as many interested parties as possible, including manufacturers, users, consumers and regulators of a particular material, product, process or service.

Standards provide agreed ways of naming and describing a specific product. They also provide uniform methodologies to measure, test, report and assess the implementation of how to make and distribute a product.

European standards are voluntary and only become legally binding if national or subnational governments establishes laws or regulations that specifically mandate compliance with the safety standards[7]. In other countries, in the absence of specific laws or regulations, they may be entirely voluntary. Throughout Europe, while standards are not mandatory they are considered as one of the ways by which conformity to national regulations is achieved[8].

Standards bodies' aim for standards is to:

- Enhance the safety of products;
- Provide basic support for commercialisation, markets and market development;
- Assure quality, safety, interoperability and reliability of products, processes and services;
- Provide a technical basis for procurement;
- Guarantee technical support for appropriate regulation and can lead to variety and cost reduction through optimisation and best practice.

The majority of standards take shape as technical specifications and test methods. However, it has been increasingly recognised over the past few decades that standards can contribute far more to business and society broadly.

It is important to recognise that the actual text of a safety standard does not necessarily represent absolute requirements. In the introduction to the IEC 60335-series product safety standard, the following is stated:

*"An appliance that complies with the text of this standard will not necessarily be considered to comply with the safety principles of the standard if, when examined and tested, it is found to have other features that impair the level of safety covered by these requirements".*

This means that one should not rely on the text within the safety standard to provide sufficient criteria to ensure that the equipment is "safe". It is the responsibility of the manufacturer and installer to ensure that all aspects have been suitably addressed.

*"An appliance employing materials or having forms of construction differing from those detailed in the requirements of this standard may be examined and tested according to the intent of the requirements and, if found to be substantially equivalent, may be considered to comply with the standard".*

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[7] The society for standards professionals website, section "*What are voluntary standards?*". Last retrieved 27/09/18 at http://www.ses-standards.org/?58

[8] UN Ozone Secretariat (2017). *Briefing Note 1 - Safety standards relevant to Refrigeration, Air-Conditioning and Heat Pump Equipment*. Last retrieved 27/09/18 at http://conf.montreal-protocol.org/meeting/workshops/safety-and-standards/presession/briefingnotes/safety_standards_relevant_to_refrigeration_ac_and_heat_pump_equipment.pdf

In other words, if it is preferred to design the product in a manner that does not literally comply with the text of the standard, but the approach taken does not create a greater risk than if the literal interpretation was applied, then that alternative design can nevertheless be deemed to comply with the standard.

This statement is a recognition that the safety requirement cannot necessarily reflect all possible ways that a certain level of safety can be achieved in a cost-effective and ergonomic manner.

Moreover, it recognises that as technologies develop, other means by which an equivalent level of safety can be achieved will evolve and these should not be excluded.

### 2.1.1 Standardisation development organisations

Standards are developed at the international, regional, national and other levels by a variety of organisations. These organisations are independent of governments, industry, associations and the private sector.

At the international level, the International Organisation for Standardisation (ISO) and the International Electrotechnical Commission (IEC) are the main bodies that publish refrigeration, air conditioning, and heat pump (RACHP) safety standards.

At the European (regional) level, European Standards Organisations (ESOs) are formed by three key organisations, which have been officially recognised by the European Union and the European Free Trade Association (EFTA) as being responsible for developing and defining voluntary standards at European level. These include the European Committee for Standardisation (CEN), the European Committee for Electrotechnical Standardisation (IEC) and the European Telecommunications Standard Institute (ETSI).

In addition to the international and European (regional) standardisation bodies, many countries have their own national standardisation bodies. Usually these national standardisation bodies are the contact points for the regional and international organisations developing standards. The main role of the national standardisation bodies is to produce or review their own standards. Bodies can be independent or linked to the national government. Standards issued at the national level generally have priority over regional and international standards.

Examples of national standardisation bodies in European countries include the German Institute for Standardisation (DIN), the British Standardisation Institute (BSI). In North America, Underwriters Laboratories (UL), and the American National Standards Institute (ANSI) are the most important national standardisation bodies.

### 2.1.2 Levels of standards

Important “core” standards are now set at the regional and/or international level. The core standards are often used to produce national or regional standards. They are usually consistent with the international standards but they are often adapted to suit national or regional circumstances. International standards are rarely used directly.

If the national standardisation bodies adopt a standard, its name and number may be changed to match the national numbering system.

Significantly, many countries will include national modifications or deviations, for example, where requirements of the international standard conflicts with national legislation.

In the case of regional standards, such as within Europe, the international standard may be modified before it is adopted and then further modified at national level in the case of conflicts with specific national laws[9].

Some countries have their own nationally developed RACHP safety standards[10], which may be similar or substantially different from the international standards in terms of technical requirements and/or structure and approach.

Since many companies operate internationally, international standardisation bodies try to provide so-called 'harmonised' RACHP standards, so that national variations are kept to the minimum[11].

### 2.1.3 Types of standards

There are two main types of standards that apply specifically to Refrigeration, Air-Conditioning and Heat Pump (RACHP) systems.

- Group standards (also referred to as generic or horizontal standards): These provide rules that can be applied to most parts of the RACHP market;
- Product standards (or vertical standards): These only cover specific types of equipment within a sector or sub-sector of the RACHP market, e.g. domestic refrigerators.

In addition to these RACHP standards, other supplementary standards may be applicable to the RACHP market or sector. For instance, standards related to components, jointing methods, pressurised systems that apply to RACHP equipment, among others[12].

The safety requirements specified within standards can be prescriptive or performance-based[13]. A prescriptive standard requires that each component is built to certain constructional requirements. A performance standard requires that the equipment as a whole, or in parts, perform to a certain criteria.

Often, a given standard may comprise some requirements that are prescriptive and some that are performance-based. An example of a prescriptive requirement is a maximum refrigerant charge limit, which is specified on the assumption that it is sufficiently small to minimise the risk that a flammable concentration will arise on a room floor in the event of a leak.

Conversely, a performance-based requirement would be to specify that a flammable concentration on a room floor shall not arise in the event of a refrigerant leak and it is then up to the manufacturer to test and evaluate what quantity of refrigerant or other mitigation strategies can be used without exceeding that criterion.

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[9] ISO/IEC (2005). *Regional or national adoption of International Standards and other International Deliverables – Part 1 : Adoption of International Standards*. Last retrieved 27/09/18 at https://www.iso.org/files/live/sites/isoorg/files/archive/pdf/en/iso_iec_guide_21-1_2005.pdf

[10] UNEP (2014). *International standards in refrigeration and air-conditioning : An introduction to their role in the context of the HCFC phase-out in developing countries*. Last retrieved 27/09/18 at http://www.unep.fr/ozonaction/information/mmcfiles/7679-e-International_Standards_in_RAC.pdf

[11] UL website, section "*Harmonizing standards*". Last retrieved 27/09/18 at https://ulstandards.ul.com/about/harmonizing-standards/

[12] UN Ozone Secretariat (2017). *Briefing Note 1 – Safety standards relevant to Refrigeration, Air-Conditioning and Heat Pump Equipment*. Last retrieved 27/09/18 at http://conf.montreal-protocol.org/meeting/workshops/safety-and-standards/presession/briefingnotes/safety_standards_relevant_to_refrigeration_ac_and_heat_pump_equipment.pdf

[13] Khazaii J. (2014). *Energy-Efficient HVAC Design - An Essential Guide for Sustainable Building*. Springer International Publishing.

There is a general rule of precedence for standards[14]. If a directly applicable product standard is available, it should be used in preference to a group standard. The requirements in a product standard are specifically adapted to the characteristics of a sub sector of the RACHP market. It is possible to use one standard and adopt clauses or requirements from another one provided there is no conflict with that standard.

### 2.1.4 Standardisation development process

The development of standards is intended to be cost-effective and timely, as well as widely recognised and generally applied. The procedures applied to the development of international standards are based on several concepts, including the following:

- **Consensus**: This procedural principle is a necessary condition for the preparation of standards that will be accepted and used widely. Although it is necessary for the technical work to progress speedily, sufficient time is required for the discussion, negotiation and resolution of significant technical disagreements. The concept of consensus is fundamental to the standards development process. Within the context of international standards[15], it is defined as: *"General agreement, characterised by the absence of sustained opposition to substantial issues by any important part of the concerned interests and by a process that involves seeking to take into account the views of all parties concerned and to reconcile any conflicting arguments"*, with a note: *"consensus need not imply unanimity"*.
- **Discipline**: It requires adherence to deadlines and the preparedness of representatives of national bodies to read and digest new proposals. It requires the national bodies to formulate their opinions in a timely manner, taking into account the interests of all those involved at the national level.
- **Cost-effectiveness**: It means taking into account the total cost of the operation of drafting and agreeing on a standard, including direct administration costs, travel costs and the value of the time spent by experts in working groups and committees.

*CEN / CENELEC*

The development of a European Standard (EN) follows several steps[16]:

- **Proposal**: Any interested party can introduce a proposal for new work. Most standardisation work is proposed through CEN / CENELEC members.
- **Acceptance of the proposal**: Once a project to develop an EN is accepted by the relevant Technical Body, or by the Technical Board, the member countries should not initiate any new projects or revise existing standards at national level within the scope of the project. This obligation is called 'standstill' and allows efforts to be focused on the development of the EN.
- **Drafting**: Once a proposal has been accepted the core work in developing the Standard begins. This often takes place in a Working Group, also called a project team or maintenance team, which consists of experts in the subject nominated by national member bodies who work together to develop a draft.

[14] Brumbaugh J.E. (2004). *Heating Systems, Furnaces and Boilers*. Audel HVAC Fundamentals, Volume 1.

[15] See ISO/IEC Guide 2:2004

[16] CENELEC website (2018), section "*The developing of European Standards*". Last retrieved 27/09/18 at https://www.cenelec.eu/aboutcenelec/whatwedo/standardsmakingprocess/index.html

- **Committee stage**: When the Working Group is satisfied that the draft is ready for wider review it is circulated to the national members for comment and/or vote. During the committee stage a project may go through several drafts.
- **Enquiry – Public comment at national level and weighted vote**: Once the draft of an EN is approved at the committee stage, it is released for public comment and vote, a process known as the 'Enquiry'. During this stage, everyone who has an interest (e.g. manufacturers, public authorities, consumers, etc.) may comment on the draft. These views are gathered by the members who then submit a national position by means of a weighted vote and which is subsequently analysed by the Technical Body. If the results of the Enquiry show a 100% approval for the EN then the European Standard will be published.
- **Adoption by weighted Formal Vote**: If the results of the Enquiry show that the draft EN requires technical reworking, and the results of the Enquiry are not 100% approval then the Technical Body updates the draft and re-submits it for another weighted vote, called the Formal Vote.
- **Publication of the EN:** Following the approval of the EN, either from the Enquiry or the Formal Vote, the EN then is published. A published European Standard must be given the status of a national standard in all member countries, who also have the obligation to withdraw any national standards that conflict with it. This guarantees that a manufacturer has easier access to the market of all the member countries when applying European Standards and this also applies whether the manufacturer is based in a member's territory or not.

European Standards are made available in three official languages: English, French and German. National Committees can translate standards in their own language.

To ensure that a European Standard is still current it is reviewed within five years of its publication. This review results in the confirmation, modification, revision or withdrawal of the EN.

*ISO/IEC*

The main international bodies on standards, the International Organisation for Standardisation (ISO) and the International Electrotechnical Commission (IEC), have similar steps for development and drafting of standards.

- **Proposal stage**: A New Work Item Proposal (NP) is submitted in the form of proposed text for either a new standard or an amendment to an existing standard. The New Work Item Proposal is accepted if a simple majority of participating members (P-members) are in favour and there is sufficient commitment from National Bodies to participate in the development of the project.
- **Preparatory stage**: The preparatory stage leads to a Working Draft (WD) developed by a Working Group (WG). The preparatory stage ends when a WD is available for circulation to the members of the Technical Committee or Subcommittee as a Committee Draft (CD).
  At the end of the Preparatory Stage, the committee may decide to publish the final Working Draft as a Publicly Available Specification (PAS) to respond to particular market needs. A Publicly Available Specification is permitted if there is no conflict with existing

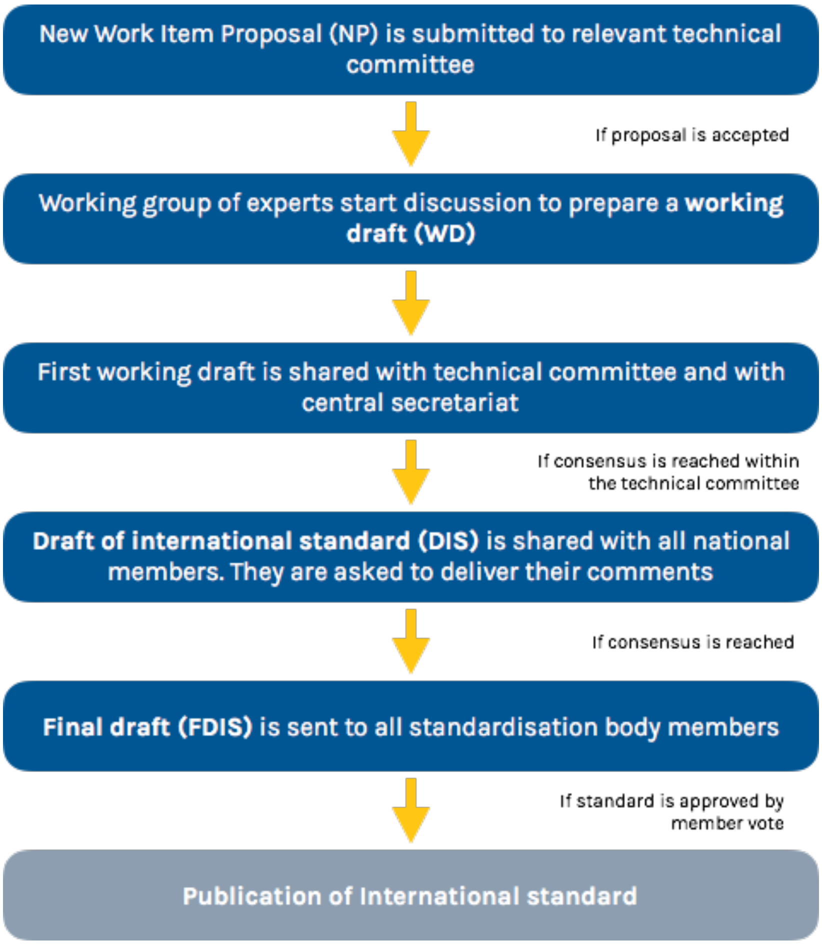
International Standards and following simple majority approval of the P-members. A Publicly Available Specification shall remain valid for an initial maximum period of three years.

- **Committee stage**: During the committee stage comments from National Bodies are taken into consideration, with a view to reaching consensus on the technical content. A committee draft is circulated to all participating and observing members for consideration over a period of 8-16 weeks. The National Bodies' comments usually lead to a revised committee draft. Consideration of successive drafts continues until consensus of the P-members has been reached or a decision to abandon or defer the project has been made. The committee stage ends when all the technical issues have been resolved and a committee draft is accepted for circulation as an enquiry draft.
  During the committee stage, if the technical issues cannot all be resolved within the allocated time, the Technical Committee or Subcommittee may consider publishing a Technical Specification as an intermediate deliverable.
- **Enquiry draft:** At enquiry stage, the draft – Draft International Standard (DIS) in ISO and Committee Draft for Vote (CDV) in IEC – is circulated to all National Bodies for a 12-week vote. Votes submitted by National Bodies can be positive, negative, or abstention. An enquiry draft is approved if:
  - A two-thirds majority of the votes cast by the P-members of the Technical Committee or Subcommittee are in favour;
  - Not more than one-quarter of the total number of votes cast are negative.

  If the approval criteria are met, an ISO document proceeds directly to publication. For IEC, if no technical changes are to be made, the document proceeds directly to publication. Otherwise, a Final Draft International Standard (FDIS) is submitted. If the approval criteria are not met, a revised enquiry draft is normally developed and the procedure is repeated.
- **Approval stage** (IEC only): At the approval stage, the Final Draft International Standard is distributed within 12 weeks to all National Bodies for a 6-week vote. Votes submitted by National Bodies can be positive, negative, or abstention. If a national body votes positively, it cannot submit any comments. If a National Body finds the Final Draft International Standard unacceptable, it must vote negatively and state the technical reasons. If the Final Draft International Standard is approved, it proceeds to the publication stage; otherwise the document is referred back to the Technical Committee or Subcommittee for reconsideration in the light of the technical reasons submitted. The committee may decide to resubmit a modified draft as a committee draft, enquiry draft, Final Draft International Standard or even cancel the project.
- **Publication stage**: The approved draft (from the enquiry stage for ISO or from the approval stage for IEC) is published. This should be done within 4 weeks of approval.

The whole standard development process can take from six months to five years, in the case of major projects or when there are widely differing technical opinions.

Figure 2.1.1: Process of international / regional standard development (ISO example)




### 2.1.5 Barriers faced by the industry to participate in the standard making process

Currently, with the development of the various RACHP safety standards, there are a relatively small number of enterprises involved throughout all the stages in the development process.

Whilst there are tens of thousands of equipment manufacturers, installation and service contractors and end-users of RACHP systems and equipment, current active participation in the standards development process is in the order of a few tens of stakeholder entities.

This highlights the importance of participation from other interested parties as well.

The main reasons for the lack of wider participation of HVAC&R experts in standardisation work can be explained as follows:

1. The high investment costs involved, associated with assigning staff to continually review and comment on documents, frequent national and international travel to participate in meetings and carry out theoretical and experimental work for the purposes of drafting and supporting proposals and counter-proposals. However, it is often possible to participate remotely in meetings, whether of Working Groups, Project Teams, Technical Committees or Subcommittees;

2. Due to the process typically being drawn out over a period of several years, the benefit from that investment will take several years to manifest. It is deemed easier for enterprises to simply accept what other stakeholders formulate within a standard and fit new technology into the constraints arising from what is published;
3. Lack of knowledge of the standards development process. There is often an assumption within enterprises that standards are developed by some discrete entity, rather than the process being potentially open to almost any stakeholder.

## 2.2 Flammable refrigerant standards

There are several ranges of different circumstances in which safety issues such as flammability need to be considered. These include the following stages in a typical RACHP product lifetime:

- Equipment design;
- Equipment manufacture;
- Transport of new equipment containing flammable gases;
- Installation of new equipment;
- Normal operation during equipment life;
- Servicing and maintenance;
- Decommissioning at end-of-life.

Different safety standards may apply at different stages of the lifecycle and some of the standards may not necessarily be specific RACHP standards but other group standards aimed at different industries[17].

Safety standards working groups take account of the extra risks that could be involved during installation, servicing or decommissioning.

New equipment can be properly designed to use flammable fluids, taking relevant safety issues and safety standards fully into account. Using a flammable refrigerant to retrofit existing equipment that was designed for a non-flammable fluid can often create significant safety risks and is generally not recommended by decision-makers[18]. Furthermore, in some countries (e.g. United States), it is also prohibited for certain types of equipment.

Third party testing, inspections, approvals and certification are sometimes necessary or preferred. This depends either upon internal rules of the manufacturer or upon national regulations.

In some countries, nominated third parties must be used to verify conformity to certain safety standards, whereas in other countries self-declaration of the manufacturer or installer is considered adequate.

[17] In many countries, there are other safety related regulations that cover RACHP and may take precedence over safety standards, which is an important consideration if their requirements are more stringent than those in the safety standards. Examples may include regulations which cover flammable gases in manufacturing and process environments, transportation of dangerous goods, workers involved with the handling of flammable substances.

[18] At a recent meeting of the Multilateral Fund Executive Committee, Decision 72/17 was agreed, which stated: « anyone engaging in retrofitting HCFC-based refrigeration and air conditioning equipment to flammable or toxic refrigerants and associated servicing, does so on the understanding that they assume all associated responsibilities and risks ».

### 2.2.1 Analysis of current state and content of relevant European and International standards

Table 2.2.1: Applicability of key European and international standards

| Standard type | Group | | Product | | |
|---|---|---|---|---|---|
| **Standard** | ISO 5149 | EN 378 | IEC/EN 60335-2-24 | IEC/EN 60335-2-40 | IEC/EN 60335-2-89 |
| **Expected publish date of revision** | Published – revision date unknown | Published - revision date unknown | Published | 2019-2022 | 2019 |
| **Domestic refrigeration** | | | x | | |
| **Commercial refrigeration** | x | x | | | x |
| **Industrial systems** | x | x | | | |
| **Transport refrigeration** | x | x | | | |
| **Air-to-air air conditioners and heat pumps** | x | x | | x | |
| **Chillers** | x | x | | x | |

**EN 378 "REFRIGERATING SYSTEMS AND HEAT PUMPS"""**

EN 378 specifies the requirements for the safety of persons and property, provides guidance for the protection of the environment and establishes procedures for the operation, maintenance and repair of refrigerating, air conditioning and heat pump systems, as well as the recovery of refrigerants. CEN/TC 182/WG 6 ‘Revision of EN 378’ is the responsible technical body.

The standard applies to:

- Commercial refrigeration
- Industrial systems
- Transportation refrigeration
- Air-to-air conditioners and heat pumps
- Chillers

Table 2.2.2: Charge size limitations for A3 refrigerants under EN 378

| Equipment | | Maximum charge limit | Allowable charge |
|---|---|---|---|
| Commercial refrigeration | | 1.5kg | 0.008 x room volume |
| Industrial systems | | 2.5kg; 10kg; 25kg; unlimited* | 0.008 x room volume |
| Transportation refrigeration | | 1.5kg; 2.5kg* | 1.5kg; 2.5kg |
| Air conditioners and heat pumps | Small self-contained | 0.3kg | 0.01 x room volume |
| | Mini-split | 1.5kg | 0.04 x height x room area$^{0.5}$ |
| | Multi-split | 1.5kg | 0.04 x height x room area$^{0.5}$ |

| | | | |
|---|---|---|---|
| | Ducted split | 1.5kg | 0.04 x height x room area$^{0.5}$ |
| | Ducted split commercial | 1.5kg | 0.04 x height x room area$^{0.5}$ |
| | Hot water heating pumps | 1.5kg; 5kg; 10kg; 25kg; unlimited* | 0.04 x height x room area$^{0.5}$ |
| | Space heating heat pumps | 1.5kg; 5kg; 10kg; 25kg; unlimited* | 0.04 x height x room area$^{0.5}$ |
| Chillers | | 5kg; 5kg; 10kg; 25kg; unlimited* | N/A |

The latest version of EN 378 is EN 378:2016, published in 2016. EN 378:2016 built on the previously published version EN 378:2008, which primarily incorporated new requirements for the newly established A2L refrigerant classification.

At present, discussions are underway on several issues that are especially relevant for natural flammable refrigerants that could not be addressed during the development process of EN 378:2016, such as:

- Improved system measures, such as protection against mechanical impacts, prevention of fretting and minimisation of vibration and piping resonances;
- A minimum airflow rate, established from refrigerant type, charge amount and system characteristics, or airflow in response to an activated sensor, to prevent the formation of flammable mixtures;
- Improved charge limits for A3 refrigerants below ground, which are currently limited at 1kg for A3 refrigerants.

There is currently no clear time schedule for publication of a revised standard.

EN 378 (Part 2) provides presumption of conformity with several European Directives:

- European Directive 97/23/EC ('Pressure Equipment Directive')

- European Directive 98/37/EC (‘Machinery Directive’)

However, it should be recognised that none of the parts to EN 378 are harmonised to the ATEX (product) or ATEX (workplace) directives.

### ISO 5149 “”REFRIGERATING SYSTEMS AND HEAT PUMPS””

The scope and structure of ISO 5149 is nearly identical to that of EN 378.

ISO 5149 specifies the requirements for the safety of persons and property, provides guidance for the protection of the environment and establishes procedures for the operation, maintenance and repair of refrigerating, air conditioning and heat pump systems, as well as the recovery of refrigerants. ISO/TC 86/SC 1/WG 1 ‘Safety and environmental requirements for refrigerating systems and heat pumps’ is the responsible technical body.

ISO 5149 applies to:

- Commercial refrigeration
- Industrial systems
- Transport refrigeration
- Air conditioners and heat pumps
- Chillers

Table 2.2.3: Charge size limitations for A3 refrigerants under ISO 5149

| Equipment | | Maximum charge limit | Allowable charge |
|---|---|---|---|
| Commercial refrigeration | | 1.5kg | 0.008 x room volume |
| Industrial systems | | 2.5kg; 10kg; 25kg; unlimited* | 0.008 x room volume |
| Transportation refrigeration | | 1.5kg; 2.5kg* | 1.5kg; 2.5kg |
| Air conditioners and heat pumps | Small self-contained | 0.3kg | 0.01 x room volume |

| | | | |
|---|---|---|---|
| | Mini-split | 1.5kg | 0.04 x height x room area$^{0.5}$ |
| | Multi-split | 1.5kg | 0.04 x height x room area$^{0.5}$ |
| | Ducted split | 1.5kg | 0.04 x height x room area$^{0.5}$ |
| | Ducted split commercial | 1.5kg | 0.04 x height x room area$^{0,5}$ |
| | Hot water heating pumps | 1.5kg; 5kg; 10kg; 25kg; unlimited* | 0.04 x height x room area$^{0,5}$ |
| | Space heating heat pumps | 1.5kg; 5kg; 10kg; 25kg; unlimited* | 0.04 x height x room area$^{0,5}$ |
| Chillers | | 5kg; 5kg; 10kg; 25kg; unlimited* | N/A |

The latest version of ISO 5149 is ISO 5149:2014, published in 2014.

Currently, ISO/TC 86/SC 1/WG 1 is reviewing several technical issues that could not be addressed during the development of ISO 5149-X:2014 and emerging issues of relevance, such as:

- A proposal on charge size limits within ISO 5149-1, including requirements for the evaluation of leaked quantity of refrigerants, test method to determine refrigerant quantity, 'human comfort' and the structure of charge limits.
- Proposals for A2L refrigerants, including ventilation, allowable surface temperature, maintenance, fan dilution and increasing boundary limitations.

**IEC/EN 60335-2-24 “”PARTICULAR REQUIREMENTS FOR REFRIGERATING APPLIANCES, ICE-CREAM APPLIANCES AND ICE MAKERS””**

IEC 60335-2-24:2010 deals with the safety of the following appliances, refrigerating appliances for household and similar use; ice-makers incorporating a motor-compressor and ice-makers intended to be used in frozen food storage compartments; refrigerating appliances and ice-makers for use in camping, touring caravans and boats for leisure purposes, their rated voltage being not more than 250 V for single-phase appliances and 480V for other appliances and 24 V dc for appliances when battery operated. These appliances may be operated from the mains, from a separate battery or operated either from the mains or from a separate battery. This standard also deals with the safety of ice-cream appliances intended for household use, their rated voltage being not more than 250 V for single phase appliances and 480 V for other appliances. IEC 60335-2-24 also deals with compression-type appliances for household and similar use, which use flammable refrigerants. IEC/TC 61/SC 61C ‘Safety of refrigeration appliances for household and commercial use’ is the responsible technical body.

Product sector covered:

- Domestic refrigeration

Table 2.2.4: Charge size limitations for A3 refrigerants under IEC/EN 60335-2-24

| Equipment | Maximum charge limit | Allowable charge limit |
|---|---|---|
| Domestic refrigeration | 0.15kg | 0.15kg |

There is at present no effort to increase the maximum or allowable charge limits in IEC 60335-2-24, given the needs of refrigerating appliances for household use and ice-cream appliances.

The latest version of IEC 60335-2-24 is the amended consolidated version IEC 60335-2-24:2010+AMD1:2012+AMD2:2017, published in 2017.

**IEC/EN 60335-2-40 “”PARTICULAR REQUIREMENTS FOR ELECTRICAL HEAT PUMPS, AIR CONDITIONERS AND DEHUMIDIFIERS””**

IEC 60335-2-40 is the international standard that deals with the safety of electrical appliances for household and similar use, with a rated voltage not greater than 250V for single-phase appliances and 480V for other appliances. Appliances not intended for normal household use but that can be considered a source of danger to the public are also included within the scope. In fact, 90% of the type of products covered by the standard are usually intended for non-domestic situations and all products are regularly used in non-domestic circumstances. It is also important to note that the scope is extremely broad and that all types of air conditioners are effectively covered by the standard.

IEC 60335-2-40 deals with the safety of electric heat pumps, sanitary hot water heat pumps, air conditioners, supplementary heaters, and dehumidifiers incorporating motor-compressors and hydronic fan coil units. IEC/TC 61/SC 61D 'Appliances for air-conditioning for household and similar purposes' is the responsible technical body.

Product sectors covered:

- Air conditioners and heat pumps
- Water heating heat pumps
- Chillers

Table 2.2.5: Charge size limitations for A3 refrigerants under IEC/EN 60335-2-40

| Equipment | | Maximum charge limit | Allowable charge |
|---|---|---|---|
| Air conditioners and heat pumps | Small self-contained | 0.3kg | 0.01 x room volume |
| | Mini-split | 1kg | 0.04 x height x room $area^{0.5}$ |
| | Multi-split | 1kg | 0.04 x height x room $area^{0.5}$ |
| | Ducted split | 1kg | 0.04 x height x room $area^{0.5}$ |
| | Ducted split commercial | 1kg | 0.04 x height x room $area^{0.5}$ |
| | Hot water heating pumps | 1kg; 5kg* | 0.04 x height x room $area^{0.5}$ |
| | Space heating heat pumps | 1kg; 5kg* | 0.04 x height x room $area^{0.5}$ |

| | | |
|---|---|---|
| Chillers | 1kg; 5kg* | 1kg; 5kg |

The latest version of IEC 60335-2-40 is the consolidated amended version IEC 60335-2-40:2013+AMD1:2016, published in 2016.

IEC/TC 61/SC 61D/WG 16 'Address A2 and A3 refrigerants' of IEC/TC 61/SC 61D is currently working on amendments to IEC 60335-2-40.

IEC/TC 61/SC 61D/WG 16 began in September 2015 to develop requirements to address charge sizes for A2 and A3 refrigerants and mitigation measures, such as:

- While the maximum charge size remains (26 multiplied by the lower flammability limit), options have been included to increase allowable charge size using improved system tightness, minimum airflow and determining the maximum releasable charge;
- Improved system tightness, such as protection against mechanical impacts, prevention of fretting and minimisation of vibration and piping resonances;
- Include a minimum airflow rate, established from refrigerant type, charge amount and system characteristics, or airflow in response to an activated sensor, to prevent the formation of flammable mixtures;
- Charge leak test method, so that the allowable charge limit can be based on the amount of refrigerant that is not retained by the system in the case of a leak.

The IEC/TC 61/SC 61CD/WG 16 proposal is in CD stage and expected to be published in 2019-2022.

The IEC/TC 61/SC 61D/WG 9 "Addition of coverage for A2L refrigerants" began work in 2011, to develop additional requirements for A2L refrigerants. The Final Draft International Standard (FDIS) version was launched for vote in October 2017, and the standard was published in January 2018.

**IEC/EN 60335-2-89 “”PARTICULAR REQUIREMENTS FOR COMMERCIAL REFRIGERATING APPLIANCES WITH AN INCORPORATED OR REMOTE REFRIGERANT CONDENSING UNIT OR COMPRESSOR””**

IEC 60335-2-89 specifies safety requirements for electrically operated commercial refrigerating appliances that have an incorporated compressor or that are supplied in two units for assembly as a single appliance in accordance with the manufacturer's instructions (split system). IEC/TC 61/SC 61C 'Safety of refrigeration appliances for household and commercial use' is the responsible technical body.

Product sector covered:

- Commercial refrigeration

Table 2.2.6: Charge size limitations for A3 refrigerants under IEC/EN 60335-2-89

| Equipment | Maximum charge limit | Allowable charge |
|---|---|---|
| Commercial refrigeration | 0.15kg | 0.15kg |

The latest published version of IEC 60335-2-89 is the amended IEC 60335-2-89:2010+AMD1:2012+AMD2:2015, which introduced requirements for transcritical $CO_2$ systems and an 'enhanced flexing test' and aligned content with the updated version of IEC 60335-1.

A Committee Draft for Vote (CDV) on IEC 60335-2-89, which was voted on and approved by national committees in July 2018, contains several modifications relevant for the use of flammable refrigerants in commercial refrigeration systems:

- An increase in the allowable charge limit from 150g to approximately 500g of A3 refrigerants per circuit ('13 multiplied by the lower flammability limit of the refrigerant'). Practically this equates to an allowable charge per circuit of 494g of R290, 559g of R600a and 598g of R1270, for example.
- An increase in the maximum charge limit of A2L refrigerants to 1.2kg per circuit. A similar allowable charge calculation per circuit would have resulted in an allowable charge of approximately 4kg for A2L refrigerants, but testing by the Air-Conditioning Heating and Refrigeration Technology Institute (AHTRI) had demonstrated high risks for those charge sizes. As a result, a maximum charge limit of 2.4kg was proposed to limit risks and match the cooling capacity of A3 refrigerants at a given charge size per circuit.
- Improved system tightness measures, such as protection against mechanical impacts, prevention of fretting and minimisation of vibration and piping resonances.
- A surrounding concentration test, in which a leak is simulated from critical leak point and measured at 5 cm from the appliance boundary.

The next step is to address the comments from the CDV process during the next SC61C subcommittee meeting in Busan, South Korea, in October 2018. The subcommittee will then decide, based on whether the issues raised by the comments are resolved, whether the charge-limit draft should go to a final vote phase (FDIS) by the end of 2018. If so, the standard could be published in early 2019 assuming a successful final vote.

### 2.2.2 Other relevant national standards

The following section reports some standards relevant to application of hydrocarbons in some European and non-European countries:

Table 2.2.7: Overview of some relevant national legislations and standards

| France | |
|---|---|
| Établissements Recevant du Public, ERP, Article CH35 | The Interior Ministry of France - more specifically the General Direction for Civil Security and Crisis Management - published in December 2017 a practical guide on the fire safety for stores and shopping malls. The guide deals with the use of flammable and mildly toxic refrigerants (A2L, A2 and A3 according to EN 378) in plug-in units installed in the areas open to the public in stores and shopping malls. Under the new guidance, for instance, the maximum permitted R290 charge per circuit is 1.5 kg in circuits located on the ground floor of the retail facility and 1 kg in circuits located in underground areas accessible to the public (in line with updated European standard EN 378-1). The guide is targeted at designers, building owners, building operators, equipment installers, technicians, safety officials, and administrative authorities. |
| **Italy** | |
| • D.M. 9/04/1994 (Hotels);<br>• D.M. 27/07/2010 (Malls);<br>• D.M. 19/08/1996 (Buildings for Public Shows);<br>• D.M. 18/09/2012 (Hospitals);<br>• D.M. 26/08/1992 (Schools);<br>• D.M. 22/02/2006 (Offices);<br>• D.M. 16/07/2014 (Kindergartens);<br>• D.M. 7/07/2014 (Airports);<br>• D.M. 18/07/2014 (Freight). | Safety legislation in Italy forbids the use of flammable refrigerants in certain types of public access buildings (e.g. hotels, schools, offices, etc.). The rules specifically affect central and localised air-conditioning. They do not apply to refrigeration or heating-only heat pumps. |
| **Spain** | |
| Royal Decree 138/2011 | The requirements set for A3 refrigerants are similar to those in EN 378 except in public access areas where it is only possible to use sealed systems. This creates a barrier to non-sealed systems using hydrocarbons e.g. small split air-conditioning.<br><br>The maximum charge per installation is 2.5kg, where installation refers to the entire retail space. |

| USA | |
|---|---|
| • UL 60335-2-24 (former UL 250) "Household and similar electrical appliances"<br>• UL 471 "Commercial refrigerators and freezers | UL standards limit the use of hydrocarbons to 150g in a single refrigeration circuit.<br><br>UL 60335-2-24 was revised in late April 2017 to increase the hydrocarbon charge allowed in U.S. domestic refrigerators to 150 g from previous 57 g (the amount allowed under the previous standard, UL 250). In August 2018, the U.S. Environmental Protection Agency (EPA) published a final rule linking the UL 60335-2-24 to the Significant New Alternatives Policy (SNAP) program, making it possible to sell domestic fridges with up to 150g of hydrocarbons in the US market.<br><br>UL 471 is being replaced in 2022 with UL 60335-3-89, which for the moment is the same charge (150g) as IEC 60335-2-89.<br><br>For UL 60335-2-40 for AC, it contains the 114 g charge limit from UL 484.<br><br>A UL 484 Task Group on flammable refrigerants was assembled and chaired by EIA to discuss future changes for A2 and A3 refrigerants and concluded that there should be a CANENA WG established in 2019 once the IEC 61D WG16 proposal for A2/A3 refrigerants reaches the CDV stage. |
| ANSI / ASHRAE 15 "Safety standards for refrigeration systems | ANSI/ASHRAE 15 currently places restrictive limits on the use of flammable refrigerants in many building types and particularly on A3 refrigerants which require approval from a local jurisdiction to install in amounts greater than 150 grams. Changes to accommodate broader use of A2L refrigerants have been prioritised under this standard, while no proposed changes to accommodate greater use of A3 refrigerants have been submitted. ASHRAE 15 is adopted into language for model building codes published by the International Code Council (ICC), which are in turn legally adopted by most states and local jurisdictions in the United States. |

## 2.3 Barriers posed by standards to the use of flammable refrigerants

### 2.3.1 Charge size limits for human comfort

**Standards impacted**

- EN 378
- ISO 5149
- IEC/EN 60335-2-40

**Description**

EN 378, ISO 5149 and EN 60335-2-40 use a formula to determine the charge size limit applied to flammable refrigerants for air conditioners, heat pumps and dehumidifiers when in 'human comfort' conditions.

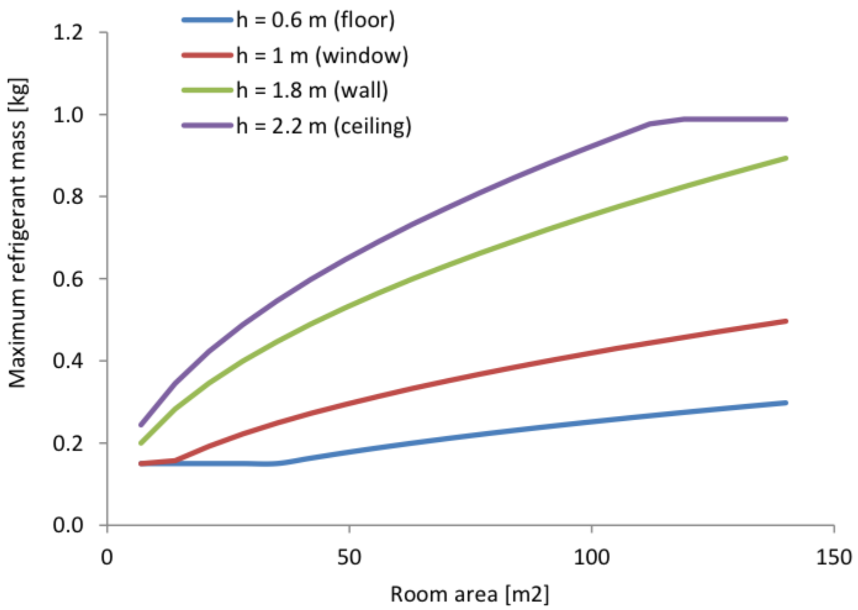
$$m_{max} = 2.5 \times LFL^{5/4} \times h_0 \times A^{1/2}$$

Where:

$m$ = Refrigerant charge amount in the appliance in kg;
$m_{max}$ = Allowable maximum charge in kg;
$LFL$ = Lower Flammable Limit in kg $m^{-3}$
$h_0$ = Fixed height value
$A$ = Room area in $m^2$

The mass of refrigerant within a system is limited as function of the installation height of the indoor unit, the area of the room and the lower flammability limit of the refrigerant. In practice, this means that the charge size is smaller for units installed closer to the floor and a larger refrigerant charge size demands a greater room area. The result of the formula on systems containing R290 is presented in the figure below.

Figure 2.3.1: Maximum R290 charge mass for a given installation height and room area



Note that there is a lower bound of 0.15kg, which is present since systems containing less than 0.15g can be placed anywhere without restrictions on room size. There is also an upper bound limit, approximately 1kg for R290, which limits the extent of charge sizes.

Figure 2.3.2: R290 maximum charge versus cooling capacity

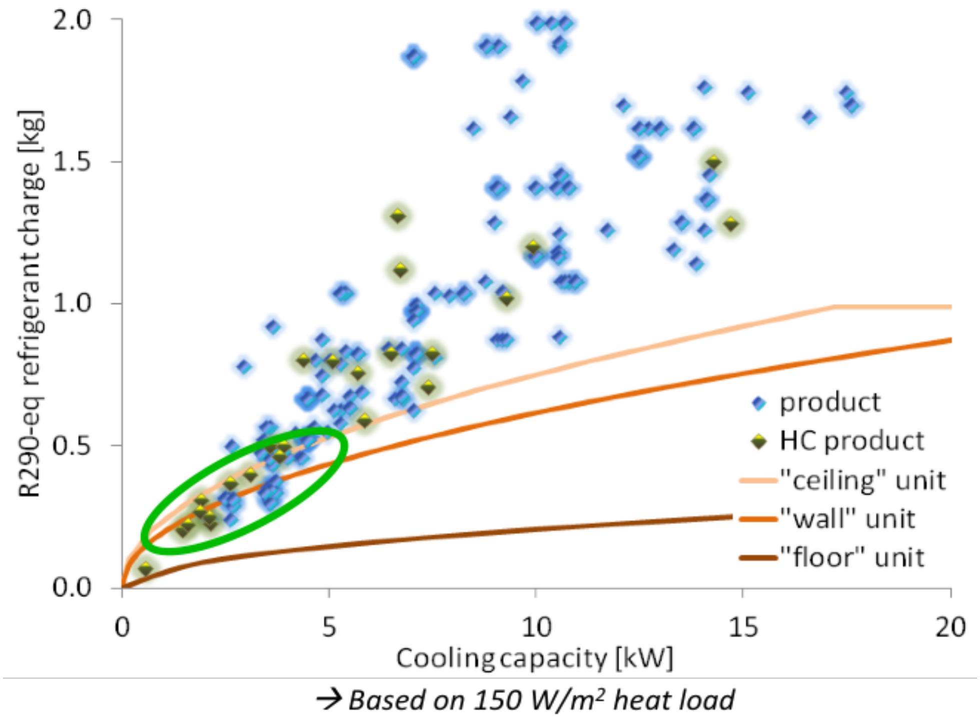
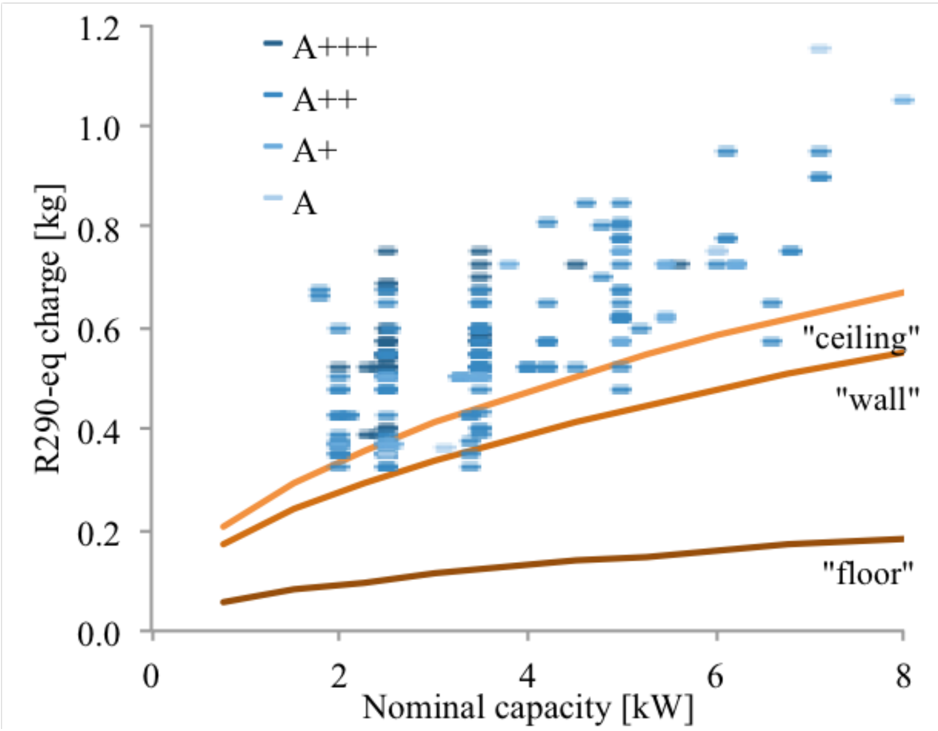



Figure 2.3.2 includes data-points for approximately 250 split air conditioner products, with nominal cooling capacity at standard rated conditions against refrigerant charge. Some data-points are for HC R290 products, whereas the majority are R410A or R470C products with the refrigerant charge adjusted downwards as if the systems utilised R290 (employing a charge ratio of approximately 0.45, based on experimental work). It is evident that only smaller capacity products can achieve sufficiently low refrigerant charges that would be compliant with safety standards.

A further elaboration of this is shown in Figure 2.3.3 where data-points for all the products in the Eurovent database for split AC are used. Charge sizes were again adjusted as if they charged with R290 (broadly according to ratio of R290 to HFC liquid densities) and assuming a specific cooling load of 150 W/m$^2$. Products are identified according to energy label rating. Obviously, the products have not been designed specifically for R290, so charge size optimisation may not be as thorough as if they were R290 products. However, it is clear that the 'preferred' charge amount is substantially greater than what the standards permit. Even though some are on the border this is off-putting manufacturers since there is no margin for imprecise matching, over-charging following service, etc.

Figure 2.3.3: R290 equivalent charge versus nominal capacity for split AC




The formula contains the following assumptions:

- **Charge leak rate**: The formula has an implicit assumption that the refrigerant charge leaks from the system in four minutes. This assumption does not consider a wide number of factors that influences the mass flow rate (hole-size, tightness of systems, internal pressure, system geometry, refrigerant phase, operating mode, etc.).
- **Formula assumptions:** There are several assumptions implicit within the formula (gas tight room, totally quiescent conditions, entire charged amount leaks, leaked gas is warmed to ambient conditions, vapour phase only, instantaneous leak hole, etc.), which, taken in isolation or paired, are acceptable, but from a probabilistic approach are unrealistic to consider in combination.
- **Risk**: The assumption of the formula approach is that the risk is solely a function of the refrigerant charge amount. However, the risk is in fact determined by several other factors and design features (forced airflow, shut-off valves, pump-down cycles etc.), which can be established to minimise risk by several orders of magnitude, rather than limiting risk to the charged amount.
- **Pipe length**: Charge sizes in the data are based on standard pipe lengths (typically 5 m, or 7.5 m), so if longer piping is required then the available charge size for the unit capacity is restricted further.
- **Reversible air-conditioning systems**: Previously the majority AC systems were cooling only, whereas the trend is now moving towards reversible systems (i.e., heating and cooling). To achieve a sufficiently high heating capacity, the refrigerant charge has to be greater than the 'optimum' charge for cooling only units and furthermore, the use of mini-channel heat exchangers (that can be used for condensers to reduce charge size) and not practicable for use as evaporators in reverse cycle systems.
- **Energy Efficiency**: Minimum efficiency requirements and energy labelling, both in

Europe and globally, are pushing units towards improved efficiencies. Beyond techniques, such as variable speed compressors, incremental rises in compressor efficiency, improvements in heat exchanger surfaces and circuitry and control methods, the main option to improve system efficiency is increase the size of heat exchangers, which necessarily demands greater refrigerant charge.

### 2.3.2 Charge restrictions below ground

**Standards impacted**

- EN 378
- ISO 5149

**Description**

For almost all types of systems using natural flammable refrigerants (A3), there is a restriction on the amount of refrigerant in a refrigeration system below ground level of 1 kg. There is no such restriction for any other type of refrigerant despite them also posing risk.

A notable proportion of buildings have basements, or cellars. Basements, cellars and other utilised areas below ground level are frequently used to house refrigerating systems, including:

- Heat pumps in residential and non-residential buildings
- Chillers in residential and non-residential buildings
- Integral refrigeration systems in supermarkets and retail centres
- Air conditioning equipment in offices and laboratories

Many of these types of refrigeration systems may normally utilise systems that require a refrigerant charge of more than 1 kg of natural flammable refrigerants. For enterprises that wish to have an entire range of products using natural flammable refrigerants, this restriction imposes economic implications where they must retain products using non-flammable refrigerants in case of an installation below ground level.

With reference to Directive (94/9/EC) on ‘equipment and protective systems intended for use in potentially explosive atmospheres’ (ATEX), the ATEX guidelines, or any of the ATEX-harmonised standards such as EN 60079-0, EN 60079-10-1, EN 60079-14, etc., there are no specifications that prohibit the use of flammable gases below ground level. The ATEX Directive does require that a risk assessment is done, and where necessary, additional safety measures must be implemented.

While it is good practice to limit the storage of denser than air flammable materials below ground, as dispersion of a release is not as easy as above ground, provided that the normal criteria, such as the quantity not exceeding some fraction of the LFL and/or additional and fail-safe safety measures are applied, there should be no such restriction.

By comparison with other refrigerants, it appears that the constraint on natural flammable refrigerants is unbalanced. For example, the occurrence of fatalities from asphyxiation from class A1 refrigerants is well known, yet there is no restriction. Also, if the risk of flammability were an issue, the limit would be applied for other flammable refrigerants as a function of LFL (e.g., ‘m2’, ‘m3’, etc.). This is particularly appropriate as the other flammable refrigerants (A2s and A2Ls) have densities much greater than A3 refrigerants and are thus far more difficult to disperse (i.e. are more prone to stratification or pooling).

Remarkable, then, to note that the new revised EN378-1 will not have the restriction to use less than 1 kg of flammable refrigerant in below-ground applications.

### 2.3.3 Systems with less than 150g installed without restriction of room size

**Standards impacted**

- EN 378
- ISO 5149
- IEC/EN 60335-2-40
- IEC/EN 60335-2-89

**Description**

For systems installed without restrictions of room size there is a maximum charge size limit of 150g for natural flammable refrigerants (A3). It is now recognised that the constraint of 150 g prevents a proportion of products from using natural flammable refrigerants, constraining technological progress and product development As such, there is a significant need of manufacturers and end-users for the impacted standards to permit a greater charge size.

Although in some cases it may be feasible to specify minimum room sizes, this is not practical for small appliances as they are predominately not installed by professional installers; rather they tend to be rolled or placed into position by non-specialist workers. (If the design safety of the appliance is dictated by room size then it will in many cases be undermined by the market activities.)

Furthermore, there is a significant advantage with an absence of minimum room sizes in terms of third party compliance (i.e., who cannot confirm compliance of the installation, only the product).

- Simply the mass of refrigerant in isolation does not constitute the flammability risk associated with a product.
- There is no reason why 0.151 kg represents a set-change in risk compared to 0.149 kg.
- The risk is far more influenced by other parameters such as airflow, leak tightness, etc.
- Originally, the 0.15 kg value originated from the appliance standard (EN 60335-2-24) for domestic fridge/freezers. While it is still relevant for such appliances covered by that standard, it is imposing a constraint for commercial refrigeration appliances.

### 2.3.4 Charge size for large systems

**Standards impacted**

- EN 378
- ISO 5149
- IEC/EN 60335-2-40

**Description**

Within the standards impacted there is an upper bound on refrigerant charge sizes limits, depending upon the occupancy type and location characteristics of the system. These values range from 1.5 kg to 25 kg.

In some cases, these limitations are not a problem, in others they are. For systems with all or some of their refrigerant-containing parts in the occupied space in occupancy A or B, the limits for A3 refrigerants are 1.5 kg and 2.5 kg, respectively. Ordinarily, the same system may be applicable to occupancies that are categorised as A or B. However, if a specific system contains, for example 1.6 kg, then it would only be permissible in occupancy B locations.

Principally there is not necessarily any notably higher risk in using a system with 1.6 kg, compared to 1.4 kg. The risk of ignition is already accounted for by limiting the quantity of refrigerant per unit of free volume within the installed space.

### 2.3.5 Harmonisation with EU legislation

**Standards impacted**

- EN 378
- ISO 5149
- IEC/EN 60335-2-40
- IEC/EN 60335-2-89

**Description**

Currently, the safety standards are harmonised with the following European safety Directives:

- EN 378: Pressure Equipment Directive (97/23/EC) and Machinery Safety Directive (2006/42/EC)
- EN 60335-2-40: Machinery Safety Directive (2006/42/EC) and Low Voltage Directive (2006/95/EC)
- EN 60335-2-89: Machinery Safety Directive (2006/42/EC); previously Low Voltage Directive (2006/95/EC)

As these standards are harmonised with these Directives, it enables manufacturers to achieve a presumption of conformity to the essential health and safety requirements.

However, as none of these standards are harmonised to the Directive (94/9/EC) 'equipment and protective systems intended for use in potentially explosive atmospheres' (ATEX), manufacturers of equipment using flammable refrigerant must first navigate through the ATEX Directive and subsequently a series of other harmonised standards, which are seldom directly applicable to refrigeration and air conditioning equipment, to comply with relevant legal requirements. Work has been undertaken for the other applicable Directives, but, yet, not for ATEX; creating a considerable bureaucratic challenge to manufacturers and installers, and imposing a sense of uncertainty in terms of their legal position.

### 2.3.6 Other aspects relevant for systems containing flammable refrigerants

In addition to the barriers discussed above, there are a series of other factors that have a relevance and cost implication for systems using flammable refrigerants.

These include:

- Electrical equipment configuration and testing
- Pressure limiting and relief devices
- Secondary and indirect systems
- System tightness
- Gas sensors
- Marking
- Flammability hazard information

# CHAPTER 3: CURRENT MARKET FOR HYDROCARBON-BASED HVAC&R EQUIPMENT

## 3.1 EU F-Gas Regulation and its impact

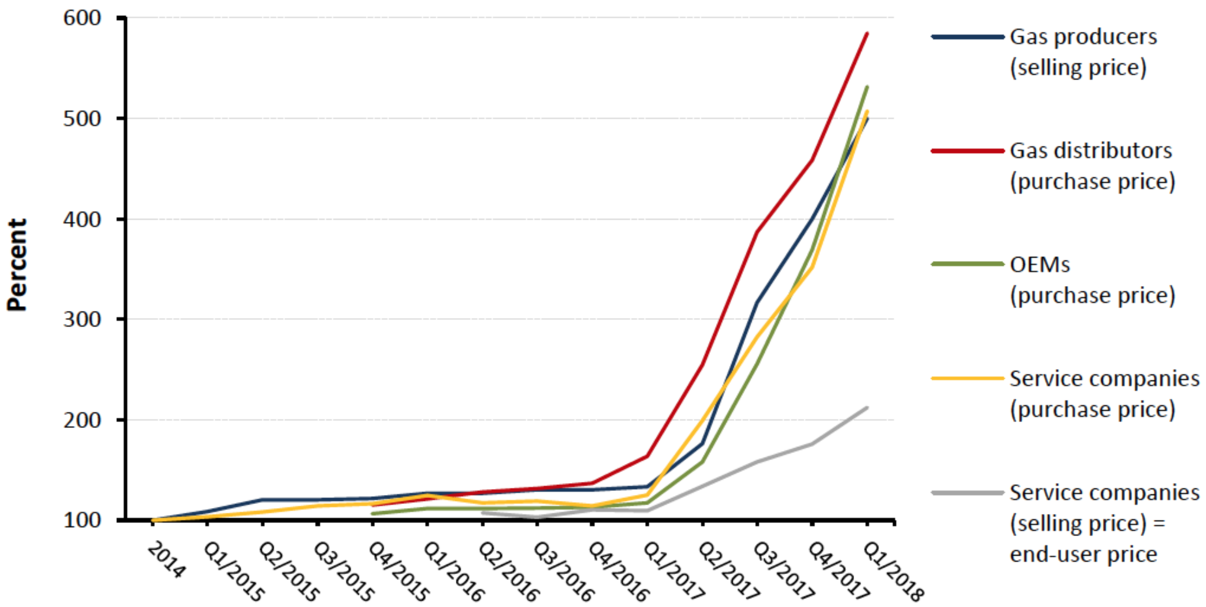
The uptake of low-GWP alternatives such as hydrocarbons in Europe is strongly influenced through legislation. At the EU level, the Regulation (EU) 517/2014 on fluorinated greenhouse gases (F-Gas Regulation) is a powerful driver for manufacturers and end-users to consider hydrocarbons for a variety of applications.

The HFC phase-down is one of the key pillars of the Regulation as it aims to reduce the amount of HFCs placed on the EU market (in $CO_2$eq) by 79% by 2030, as compared to average levels in 2009-2012. Producers and importers of f-gases are allocated annual quotas of HFCs that allow them to place a certain amount on the market.

The HFC phase-down dramatically affects the cost and availability of synthetic refrigerants with high-GWP. What the phase-down actually means is that the average GWP of HFCs will have to fall from today's 2,000 to about 400 by 2030 across all sectors. Natural refrigerants, such as hydrocarbons will therefore play a major role in achieving this target.

The first big cut in HFC quotas (37%) in 2018 has triggered a huge price increase in commonly used HFCs. While the HFC prices grew five-fold in 2017, they are expected to spike 20 times by the end of 2018 as supplies contract sharply.

Figure 3.1.1: Development of average purchase and selling prices for R134a at different supply chain levels, indexed to 2014 prices (100%) - until Q1 2018[19]




The F-Gas Regulation also introduced bans in specific sectors on new equipment using HFCs above a specific GWP that will take effect by a certain year. This measure is crucial for ensuring that the HFC phase-down targets are achieved. The HFC ban specifies the timing for each sector to shift to refrigerants with a lower climate impact, such as natural refrigerants. In the refrigeration sector, the restrictions especially target the commercial sector, where the EU

[19] Öko-Recherche GmbH (2018). Monitoring of refrigerant prices against the background of the F-gas Regulation (EU) No 517/2014.

foresees that as of 2022 new equipment will use refrigerants with a GWP below 150 in both plug-in applications (e.g. refrigerated showcases, bottle coolers, vending machines) and in larger centralised systems in supermarkets (with some exceptions). This ban is already having an impact on the increased availability of hydrocarbon-based equipment, especially in plug-in systems as the industry anticipates that the commonly used HFCs will be banned soon in new equipment.

Table 3.1.1: HFC bans relevant to commercial refrigeration under the EU F-Gas Regulation

| Equipment | GWP limit | Date of prohibition |
|---|---|---|
| Stationary refrigeration equipment (except products designed to cool below -50°C) | 2,500 | 1 January 2020 |
| Refrigerators and freezers for commercial use (hermetically sealed) | 2,500 | 1 January 2020 |
| | 150 | 1 January 2022 |
| Centralised commercial refrigeration (≧40kW), except in the primary refrigeration circuit where f-gases with GWP < 1,500 may be used | 150 | 1 January 2022 |

In the air-conditioning sector, the HFC ban addresses only small equipment - portable room air-conditioners and single split AC units with less than 3kg of f-gas refrigerant charge. Besides the HFC ban in portable AC, the Regulation offers little incentive for companies active in the air-conditioning and heat pump sector to shift to the lowest possible GWP alternatives, such as hydrocarbons. It is expected that this sector will start to feel the impact of the Regulation through the HFC phase-down as the prices of commonly used HFCs continue to grow.

Table 3.1.2: HFC bans relevant to air-conditioning under the EU F-Gas Regulation

| Equipment | GWP limit | Date of prohibition |
|---|---|---|
| Movable room air-conditioning equipment | 150 | 1 January 2020 |
| Single split air-conditioning systems (< 3kg of f-gases) | 750 | 1 January 2025 |

The impact of the F-Gas Regulation on the uptake of hydrocarbons is also reflected in the findings of the survey, which are detailed in section 4.1 of this report. Over half of respondents indicated they already work with hydrocarbons to some extent. Out of those that do not yet offer or use products with hydrocarbons, over 50% plans to start in the future, while about 30% is undecided. More than two thirds of those that will start working with hydrocarbons plan to do that by 2020. This finding demonstrates that the industry anticipates the prohibitions and growing HFC prices under the F-Gas Regulation, but also expects the safety standards to allow for this transition within two years.

## 3.2 Drivers & barriers for hydrocarbons

Understanding the drivers and barriers that have an impact on the choice of stakeholders to work with hydrocarbon systems and equipment is important. Identifying the most common barriers can provide direction on where to focus in finding solutions to problems, in order to increase the penetration of hydrocarbon systems. Similarly, knowing the drivers that actually are successful in incentivising stakeholders can help in order to replicate them.

### 3.2.1 Drivers

Respondents who are currently working with hydrocarbons were asked about the drivers for doing so. "Environmental impact (direct and indirect emissions)" and "Compliance with current/future legislation" ranked the highest with an average score of 4.4 and 4.1 out of 5 respectively. Moreover, "Energy efficiency gains" ranked 3rd with an average score of 3.8 out of 5.

It is clear from these indications that stakeholders believe that hydrocarbons are energy efficient, sustainable and future-proof refrigerants. From interviews with manufactures it was noted that end-users do initially become interested in hydrocarbon refrigerants for environmental and legislative reasons. However, they would not choose to install such systems unless the efficiency incentive was on the table, which has a direct impact on the life cycle cost and return on investment. Various case studies have revealed that hydrocarbon refrigerant-based systems have high efficiency due to a combination of their thermodynamic properties, as well as technological developments of various system components (e.g. variable speed compressors).

“Customer demand” ranked as the 4th most important driver for companies to work with hydrocarbons. This is inconsistent with the barriers scores, where “Lack of customer demand” also ranked high. Interestingly, from interviews with manufacturers it became clear that the customer demand can be both a driver and a barrier, essential depending on the end-users’ level of awareness and experience with hydrocarbon-based technology. Demand for hydrocarbon-based systems comes primarily from large end-users who have already had some experience or knowledge through their network about such systems. Thus, larger or well-connected manufacturers are able to benefit from such demand more easily. Other manufacturers, who are supplying systems to end-users who do not trust or are not aware of the benefits of hydrocarbon-based systems, do see a much lower demand for such systems, thus viewing it as a barrier.

Table 3.2.1: (Survey question) What are the main drivers for your organisation to provide / use products with hydrocarbons? Segmented per region group. Scores from 1 (weakest) to 5 (strongest).

| Drivers | Europe | Rest of world | Worldwide |
|---|---|---|---|
| Drivers: Energy efficiency gains | 3.8 | 4.0 | 3.8 |
| Drivers: Simple design and manufacturing process | 2.8 | 2.5 | 2.7 |

| | | | |
|---|---|---|---|
| Drivers: Improved design features (forced airflow, leak tightness, shut-off valves, pump down cycles etc.) can minimise risk of the higher flammable refrigerant charge | 3.0 | 2.9 | 3.0 |
| Drivers: Simple repair and maintenance needs | 2.7 | 2.7 | 2.7 |
| Drivers: Capital cost (initial investment) | 3.1 | 2.8 | 3.0 |
| Drivers: Return on investment (life cycle cost) | 3.4 | 3.4 | 3.4 |
| Drivers: Environmental impact (direct and indirect emissions) | 4.5 | 4.1 | 4.4 |
| Drivers: Customer demand | 3.9 | 3.4 | 3.8 |
| Drivers: Availability & supply | 3.5 | 2.8 | 3.3 |
| Drivers: Compliance with current / future legislation | 4.2 | 3.8 | 4.1 |
| Drivers: Available financial incentives | 2.3 | 2.1 | 2.2 |

### 3.2.1 Barriers

Respondents to the survey who are currently not working with hydrocarbons were asked about the barriers they face. "Safety related to flammability" received the highest score, with an average of 4.4 out of 5. "Current restrictions on charge limits" also appears in the top barriers, indicating that the current standards on charge limits discourage stakeholders to work with hydrocarbons.

As expected, safety concerns and charge limits have an impact on end-users, both in terms of fear and consequently lack of widespread demand. This is verified by the 3rd and 4th highest scoring barriers that are the "Known end-consumer apprehensions" and the "Lack of customer demand".

Interestingly, initial investment costs, ROI, and energy efficiency issues rank low in the barriers table, giving an indication that the main barriers are related more to charge limits and lack of awareness, rather than related to the technology or cost of the technology.

Table 3.2.2: (Survey question) What are the reasons for your company to NOT provide / use hydrocarbon-based equipment? Segmented per region group. Scores from 1 (weakest) to 5 (strongest).

| Barriers | Europe | Rest of world | Worldwide |
|---|---|---|---|
| Barrier: Capital cost (initial investment) | 2.7 | 2.4 | 2.6 |
| Barrier: Return of investment (life cycle cost) | 2.5 | 2.3 | 2.4 |
| Barrier: Environmental impact (indirect emissions) | 1.9 | 1.9 | 1.9 |
| Barrier: Lack of customer demand | 3.4 | 3.8 | 3.6 |
| Barrier: Lack of availability & supply | 2.7 | 2.6 | 2.6 |
| Barrier: Lack of financial incentives | 2.6 | 2.5 | 2.6 |
| Barrier: Design and manufacturing process | 3.3 | 3.0 | 3.1 |
| Barrier: Repair and maintenance needs | 2.9 | 3.1 | 3.0 |
| Barrier: Safety related to flammability | 4.3 | 4.7 | 4.4 |
| Barrier: Current restrictions on charge limits | 3.6 | 4.0 | 3.8 |
| Barrier: Energy efficiency related issues | 2.4 | 2.6 | 2.5 |
| Barrier: Known end-consumer apprehensions | 3.5 | 3.9 | 3.7 |

To get a better understanding of the issues that have a significant impact and delay the uptake of hydrocarbon-based equipment, certain groups of barriers with sub-barriers were identified. All respondents to the survey were asked to answer these questions, including those working or not working with hydrocarbons.

Barriers are grouped as follows:

- **Awareness barriers:** Awareness of the available technology and the potential benefits of hydrocarbons. With the current availability of new technologies, it is not always easy for end-users to be aware of all the various options or to have the knowledge of how they can be benefited from them.

- **Technical knowledge barriers:** Technical knowledge and skills of those involved in the choice, implementation, and operation of hydrocarbon-based equipment. Stakeholders involved in the choice and utilisation of heating and cooling systems, often lack the required knowledge to properly operate and maintain them in the best possible way. Training and hands-on experience is key for hydrocarbon refrigerant-based systems.

- **Technology readiness barriers:** Readiness of current available technology in terms of component availability, cost competitiveness, and safety levels.

- **Standards & legislation barriers:** Standards and legislation are preventing wider use of hydrocarbons. From restriction posed by standards on charges allowed to lack of incentives from legislation / government bodies and initiatives, which can play an important role in the positioning of hydrocarbons in the refrigerant market.

Standards and legislative barriers appear to have the highest average score, with a few of the highest ranking sub-barriers. The major barrier identified relates to the current maximum charge limits on hydrocarbons, which are more restrictive compared to other refrigerants. In turn, the current max charge size limit can constrain and slow down technological progress and product development. Manufacturers need their systems to be able to reach higher capacities than what is currently possible with the charge limits in place. Equally, they need to know that a product will not be restricted on account for the size of the room it may be placed in.

The charge limits, consequently create also another barrier by bringing in higher expenses for the manufacturers and end-users, who in order to satisfy the demand for higher capacities result in techniques such as using more than one circuit in the systems. In addition, respondents agree that the standards setting the max hydrocarbon refrigerant charge put too much focus on the refrigerants charge itself and do not consider other factors and design features that can lower the risk. Finally, the lack of sufficient harmonisation of standards with EU regulation creates a bureaucratic challenge for manufacturers and installers. This is seen as an important barrier creating restrictions for the industrialisation of the process of producing systems that can be used in various countries. It also raises uncertainty in terms of their legal position and obligations.

As it can be easily understood, the standards barrier by itself acts as a mechanism that creates a ripple effect of restrictions and hurdles for hydrocarbon refrigerants. By analysing the various barriers as seen by the stakeholders of this industry the main issue can be tracked in ineffective standards, miscommunication, and lack of awareness and correct information about hydrocarbon-based systems. These have as consequence the creation of smaller operational barriers that limit the uptake of hydrocarbons in the HVAC&R market.

According to respondents, the highest-ranking awareness barrier is again the "Concern about the flammability of hydrocarbons", reaching a high average score of 4.4 out of 5. When looking at the technology readiness barriers, the scores are fairly lower overall, with only the "Concern about technological maturity & safety" reaching an average score of 3.5 out of 5. These two barriers are somewhat complementary. Manufacturers have indicated during interviews that often the market has a misguided perception that hydrocarbon refrigerant-based systems are not technologically ready and can pose threats in regards to safety due to their flammability. Consequently, due to a multiplier effect of miscommunication this leads to fear, concern, and lack of awareness about true safety levels and possible dangers that hydrocarbons can pose as refrigerants.

In addition, concerns about the availability of trained technicians, as well as an actual lack of properly trained installers were identified as high ranked barriers both in the awareness group and the technical knowledge group, each with average scores higher than 3.5 out of 5. It is widely agreed by manufacturers, that installers and technicians are reluctant towards working with hydrocarbons due to flammability concerns, thus resulting in not taking proper training for the operation and safe maintenance of these systems. Although a fair number of training programmes are available in Europe[20], the slow uptake by technicians and installers is creating a bottleneck for the uptake of such systems by end-users.

Possible actions to overcome the barriers are the following set of actions:

- **Proof of safety and the danger levels of hydrocarbon refrigerants**: In order to shed light and tackle unfounded allegations for the low safety of hydrocarbon refrigerants data and analysis from the field need to be conducted. Through modelling, tests, simulation of leaks, ignition levels and more, the level of flammability danger of hydrocarbon refrigerants can be re-evaluated properly and be based on real facts.

- **National or an EU-level mandatory certification scheme**: Currently many of the schemes are 'in the shadows', seldom approved or accredited. A national or an EU-level mandatory certification scheme needs to be established.

- **Communication and awareness raising campaigns**: Facts and data can be used to increase the level of awareness among different groups of stakeholders and to end the misguided and inflated fear towards hydrocarbons as refrigerants.

Table 3.2.3: (Survey question) Rate the following awareness barriers from weak (1) to strong (5). Segmented per region group.

| Barriers: Awareness | Europe | Rest of world | Worldwide |
|---|---|---|---|
| Barriers: Lack of awareness of available technology at decision making level | 3.0 | 3.3 | 3.1 |
| Barriers: Concern about possible investment increase and long payback time | 2.6 | 3.0 | 2.8 |
| Barriers: Lack of awareness of financial support or reward schemes for energy efficiency | 2.7 | 2.9 | 2.8 |
| Barriers: Lack of awareness of possible financial savings from energy efficient hydrocarbon-based units | 2.8 | 3.1 | 2.9 |
| Barriers: Lack of awareness of the environmental benefit of hydrocarbon-based HVAC&R units | 2.5 | 2.6 | 2.5 |
| Barriers: Concern about reliability compared to H(C)FC ones | 2.6 | 3.1 | 2.8 |
| Barriers: Concern about flammability of hydrocarbons | 4.4 | 4.5 | 4.4 |

[20] Skacanova K. (2017). *Guide to natural refrigerants training in Europe 2017*. shecco publications. Last retrieved 04/10/18 at: https://issuu.com/shecco/docs/guidetrainingeurope2017

| | | | |
|---|---|---|---|
| Barriers: Concern about availability of trained technicians | 3.8 | 3.9 | 3.9 |

Table 3.2.4: (Survey question) Rate the following technical knowledge barriers from weak (1) to strong (5). Segmented per region group.

| Barriers: Technical Knowledge | Europe | Rest of world | Worldwide |
|---|---|---|---|
| Barriers: Lack of properly trained installers / technicians | 3.6 | 3.8 | 3.7 |
| Barriers: Lack of training programmes | 3.3 | 3.4 | 3.3 |
| Barriers: Lack of experienced trainers | 3.4 | 3.5 | 3.4 |
| Barriers: Lack of free or affordable educational material | 3.0 | 3.3 | 3.1 |
| Barriers: Lack of education material for different technical knowledge levels | 3.0 | 3.5 | 3.2 |

Table 3.2.5: (Survey question) Rate the following technology readiness barriers from weak (1) to strong (5). Segmented per region group.

| Barriers: Technology Readiness | Europe | Rest of world | Worldwide |
|---|---|---|---|
| Barriers: Concern about sufficient current supply | 2.3 | 2.7 | 2.4 |
| Barriers: Concern about technological maturity & safety | 3.3 | 3.9 | 3.5 |
| Barriers: Concern about initial cost of hydrocarbon systems | 2.9 | 3.2 | 3.0 |
| Barriers: Concern about component availability | 2.9 | 3.2 | 3.0 |

Table 3.2.6: (Survey question) Rate the following standards & legislation barriers from weak (1) to strong (5). Segmented per region group.

| Barriers: Standards & Legislation | Europe | Rest of world | Worldwide |
|---|---|---|---|
| Barriers: Current max charge limits on hydrocarbons mean higher expenses for the manufacturers and end-users | 3.9 | 3.6 | 3.8 |
| Barriers: Current max charge limits on hydrocarbons are more restrictive compared to other refrigerants | 4.2 | 4.1 | 4.2 |
| Barriers: The 150g max charge size limit installed without restrictions of room size constraints and slows down technological progress and product development | 4.0 | 3.7 | 3.9 |
| Barriers: Lack of sufficient harmonisation of standards with EU regulation creates a bureaucratic challenge for manufacturers and installers raising uncertainty in terms of their legal position | 3.9 | 3.8 | 3.9 |
| Barriers: Minimum energy efficiency requirements demand higher hydrocarbon charges, which with the current standards is not achievable | 3.1 | 3.2 | 3.1 |

## 3.3 Commercial Refrigeration

Commercial refrigeration systems account for units within supermarkets, which provide storage and display of perishable food and drink prior to sale. Food is stored in walk-in storages/cold rooms before they are transferred to display cases in the sales area. These units fall within two categories:

*Remote units* which are connected to a central system (compressor rack, condensing unit, chiller), and depend on that central system to provide the cooling capacity required. When it comes to the use of natural refrigerants these units often use $CO_2$ because of the higher refrigerant charge required to flow from the central system to the cold room or display cases. Nevertheless, hydrocarbons are also used, with one popular application being chillers connected to a secondary circuit with brine or glycol used to cool the cold room or cabinets.

*Plug-in units*, are systems where the entire refrigeration system and components are integrated into the cabinet. The system is sealed and compact, and it does not require any installation efforts apart from plugging the cabinet into electricity. This design requires a lower refrigerant charge, thus hydrocarbons and particularly R290 has become the refrigerant of choice for many end-users who seek to transition to natural refrigerants.

### 3.3.1 Market size of hydrocarbon-based cabinets

HFCs, especially R134a and R404A have been commonly used in commercial refrigeration equipment in Europe and still remain the most common refrigerants in existing stock. Nevertheless in new equipment, natural refrigerants namely hydrocarbons and $CO_2$ have been making inroads in commercial refrigeration applications over the last few years. The industry strongly expects this trend to intensify in the near future.

According to the data collected from leading manufacturers of hydrocarbon-based units, there are approximately 2.5 million plug-in refrigerated showcases / cabinets used in supermarkets.

Hydrocarbon plug-in systems combined with water-loop technology are gaining presence in the global market. sheccoBase, the market development arm of shecco, estimates there are more than 1,500 stores globally using the hydrocarbon water-loop technology. The technology has been widely used by end-users especially in Germany and the UK, but it's growing also in Switzerland, Finland, Sweden and other European markets.

The water-loop systems allow the end-user to remove the heat generated by cabinets to outside the store thereby reducing the air-conditioning needs. This technology is therefore particularly suitable for regions with warmer climates. The industry representatives anticipate that the review of standards to allow higher hydrocarbon charge limits per refrigeration circuit would accelerate the market uptake of this technology.

**Hydrocarbons on the rise in vending machines** [21] [22]

**Summary: Hydrocarbons are starting to make inroads into the vending machine sector, which have been until now dominated by HFCs. Until recently $CO_2$ was considered as a replacement refrigerant in response to the F-Gas Regulation.**

HFCs (mainly R134a and R404A) are used in around 80-90% of the vending machines in Europe. However, the EU F-Gas Regulation will soon put them out of the market.

An increasing number of companies are choosing hydrocarbons for their vending machines, as it was witnessed at Venditalia 2018 in Milan (Italy), one of Europe's biggest automatic distribution events. This constitutes an important market trend for a sector that counts more than 4 millions of units in Europe and has been in a continuous growth since 2013. Until the previous edition of this trade show (in 2016) the only natural refrigerant used for these applications in small quantities was carbon dioxide, partially due the interest of some major multinationals in this technology and safety considerations. Now, despite the existing design barrier an increasing number of companies is showing interest for hydrocarbons, also in light of the high costs of $CO_2$-equipment.

One of the major manufacturers in the sector showcased a new R290-based vending machine, at Venditalia in June 2018. It can contain up to 504 33cl cans, at an internal temperature between +2°C and +10°C. The R290 cooling system, at the bottom of the machine, is sealed off from the drinks and snacks compartment. Glycol circulates above to cool the produce. This system design keeps the flammable R290 away from the electronic controller unit, reducing the risk of sparks that could cause an accident.

Almost 90% of the vending machine range produced by another leading Italian-based manufacturer uses hydrocarbons. R290 is the primary choice, although some models use R600a. All the firm's vending machines that reach below 0°C temperature already use natural refrigerants. HFCs are used in only a few of their products, mostly in countries with particular technical features (e.g. voltage requirements in Japan). The continuous innovation in technology and better feasibility in reduced spaces were mentioned amongst the reasons for opting for hydrocarbons over $CO_2$.

Others explained that the loud noise coming from systems using carbon dioxide is one of the main reasons for which hydrocarbons are becoming more important in the sector.

### 3.3.2 Use of multiple refrigeration circuits

In order to overcome the current hydrocarbon refrigerant charge barrier some manufacturers have started using multiple circuits[23] in their refrigeration systems. By using more than one circuit in a refrigeration system manufacturers can at the same time comply with current standards for max refrigerant charge size and offer more refrigeration capacity, which

[21] Belluomini D. (2018). *Hydrocarbons on the rise in vending machines*. Last retrieved 07/08/18 at http://hydrocarbons21.com/articles/8360/hydrocarbons_on_the_rise_in_vending_machines

[22] Belluomini D. (2018). *Italy vending sector torn between $CO_2$, hydrocarbons*. Last retrieved 07/08/18 at http://hydrocarbons21.com/articles/8354/italy_vending_sector_torn_between_co2_hydrocarbons

[23] A circuit is the connection of the four major components required to complete a refrigeration cycle: compressor, condenser, expansion valve, evaporator

otherwise it would not be possible with only one circuit. This technique is commonly applied to plug-in units. Out of all system manufacturers responding to the survey, 62% of respondents confirmed they manufacture hydrocarbon systems with more than one refrigerant circuit.

According to the majority of survey respondents each circuit has a maximum hydrocarbon charge of 150g (with some exceptions for some manufacturers and end-users). Respondents indicated that multiple circuit units most commonly are manufactured with two circuits, with some claiming that they manufacture units with three or even four circuits. For the majority of respondents the total aggregated charge of all circuits would reach nearly 500g, making it possible to reach a cooling capacity of 5kW per plug-in unit.

The technique of using multiple circuits has both advantages and disadvantages. The advantage is that manufactures can meet the demand of end-users who wish to have units that reach a higher cooling capacity. Systems also have capacity redundancy in the event that one system fails for some reason. On the other hand each circuit needs all the components required for a complete refrigeration cycle, thus increasing the cost of each plug-in unit, especially due to the need of more than one compressor, as respondents to interviews indicated. Also when systems used variable speed drives, a greater efficiency benefit can be gained by using a single "very large" evaporator and condenser , thus enabling a smaller temperature lift, as opposed to two or more "smaller" evaporators and condensers, thereby forcing larger temperature lifts.

### 3.3.3 Cost and energy efficiency

An important parameter for choosing to invest in new systems for end-users is the initial cost. Survey participants were asked how the initial cost of hydrocarbon-based plug-in units their organisation is using / providing compared to units using current standard technology with HFCs. A high share of respondents (80%) indicated that they are on par or slightly more expensive. Close to 50% of the respondents agreed plug-in units with hydrocarbons are slightly more expensive.

On the other hand, more than 60% of respondents indicated that hydrocarbon-based plug-in units are 6-25% more energy efficient than units using HFCs, with the majority indicating 11-25% energy efficiency gains. The better energy efficiency is attributed to the thermodynamic properties of hydrocarbons as well as the system design that allows to further improve energy efficiency.

As expected, when asked about the life cycle cost of the hydrocarbon-based plug-in units their organisation is using / providing compared to units using HFC refrigerants (the current standard technology), more than 80% of the respondents indicated that the life cycle cost is on par or lower. More than 50% of respondents indicated that hydrocarbon-based systems have slightly or considerably lower life cycle costs. Savings during the life cycle are due to improved energy efficiency of systems operating with hydrocarbons.

Similar results were drawn when the questions about initial cost, energy efficiency and life cycle cost, were asked regarding remote units. 67% of respondents agreed that remote units with hydrocarbons have slightly or considerably higher initial cost than current standard technology with HFCs. The efficiency gains of remote units with hydrocarbons are spread to a wider range of 1-25%, with close to 30% of respondents indicating a 6-10% average energy efficiency gain. Consequently, the life cycle cost of remote units with hydrocarbons are estimated to be on par or lower.

The above indications, show that looking only at the initial cost of a system, is not a reliable comparison when choosing between hydrocarbon and HFC-based systems. Parameters such as energy efficiency, life cycle cost, return on investment and the protection against future regulation that can result in restrictions for synthetic refrigerants need to be taken into account.

The next two subsections on plug-ins and remote units include a detailed overview with results from the survey. Following that, a selection of case studies can be found with more detailed information on performance and characteristics about specific installations and types of systems.

### PLUG-IN UNITS

Table 3.3.1: (Survey question) How does the initial cost of the hydrocarbon-based units your organisation is using / providing compare to units using HFC refrigerants (current standard technology)? Percentages refer to percentage of respondents.

| Initial cost: Plug-in units | Europe | Rest of world | Worldwide |
|---|---|---|---|
| a) Considerably more expensive | 8.5% | 15.4% | 10.6% |
| b) Slightly more expensive | 49.2% | 42.3% | 47.1% |
| c) On par | 30.5% | 38.5% | 32.9% |
| d) Slightly less expensive | 6.8% | 3.8% | 5.9% |
| e) Considerably less expensive | 5.1% | 0.0% | 3.5% |
| **Grand total** | **100.0%** | **100.0%** | **100.0%** |

Table 3.3.2: (Survey question) What are the average energy efficiency gains of the hydrocarbon-based units your organisation is using / providing, compared to units using HFC refrigerants (current standard technology)? Percentages refer to percentage of respondents.

| Efficiency gains: Plug-in units | Europe | Rest of world | Worldwide |
|---|---|---|---|
| a) Hydrocarbon-based units are less energy efficient | 3.5% | 0.0% | 2.4% |
| b) 0 % | 7.0% | 7.7% | 7.2% |
| c) 1-5 % | 19.3% | 7.7% | 15.7% |

| | | | |
|---|---|---|---|
| d) 6-10 % | 24.6% | 26.9% | 25.3% |
| e) 11-25 % | 33.3% | 38.5% | 34.9% |
| f) 26-50 % | 12.3% | 15.4% | 13.3% |
| g) More than 50 % | 0.0% | 3.8% | 1.2% |
| **Grand total** | **100.0%** | **100.0%** | **100.0%** |

Table 3.3.3: (Survey question) How does the life cycle cost of the hydrocarbon-based units your organisation is using / providing compare to units using HFC refrigerants (current standard technology)? Percentages refer to percentage of respondents.

| Life cycle cost: Plug-ins | Europe | Rest of world | Worldwide |
|---|---|---|---|
| a) Considerably higher | 1.7% | 11.5% | 4.8% |
| b) Slightly higher | 13.8% | 15.4% | 14.3% |
| c) On par | 27.6% | 34.6% | 29.8% |
| d) Slightly lower | 31.0% | 30.8% | 31.0% |
| e) Considerably lower | 25.9% | 7.7% | 20.2% |
| **Grand total** | **100.0%** | **100.0%** | **100.0%** |

**REMOTE UNITS**

Table 3.3.4: (Survey question) How does the initial cost of the hydrocarbon-based units your organisation is using / providing compare to units using HFC refrigerants (current standard technology)?

| Initial cost: Remote units | Europe | Rest of world | Worldwide |
|---|---|---|---|
| a) Considerably more expensive | 26.6% | 20.8% | 25.0% |
| b) Slightly more expensive | 40.6% | 45.8% | 42.0% |

| | | | |
|---|---|---|---|
| c) On par | 23.4% | 25.0% | 23.9% |
| d) Slightly less expensive | 6.3% | 4.2% | 5.7% |
| e) Considerably less expensive | 3.1% | 4.2% | 3.4% |
| **Grand total** | **100.0%** | **100.0%** | **100.0%** |

Table 3.3.5: (Survey question) What are the average energy efficiency gains of the hydrocarbon-based units your organisation is using / providing, compared to units using HFC refrigerants (current standard technology)? Percentages refer to percentage of respondents.

| Efficiency gains: Remote units | Europe | Rest of world | Worldwide |
|---|---|---|---|
| a) Hydrocarbon-based units are less energy efficient | 6.3% | 0.0% | 4.7% |
| b) 0 % | 15.9% | 13.0% | 15.1% |
| c) 1-5 % | 22.2% | 21.7% | 22.1% |
| d) 6-10 % | 30.2% | 21.7% | 27.9% |
| e) 11-25 % | 22.2% | 13.0% | 19.8% |
| f) 26-50 % | 3.2% | 26.1% | 9.3% |
| g) More than 50 % | 0.0% | 4.3% | 1.2% |
| **Grand total** | **100.0%** | **100.0%** | **100.0%** |

Table 3.3.6: (Survey question) How does the life cycle cost of the hydrocarbon-based units your organisation is using / providing compare to units using HFC refrigerants (current standard technology)? Percentages refer to percentage of respondents.

| Life cycle cost: Remote units | Europe | Rest of world | Worldwide |
|---|---|---|---|
| a) Considerably higher | 1.6% | 13.0% | 4.8% |

| | | | |
|---|---|---|---|
| b) Slightly higher | 9.8% | 21.7% | 13.1% |
| c) On par | 29.5% | 39.1% | 32.1% |
| d) Slightly lower | 37.7% | 8.7% | 29.8% |
| e) Considerably lower | 21.3% | 17.4% | 20.2% |
| **Grand total** | **100.0%** | **100.0%** | **100.0%** |

**American study shows hydrocarbon charge-limit scenarios** [24]

**Summary: Fire Protection Research Foundation lists safe charge limits for self-contained cases, including 1,000 g in big-box grocery stores.**

A study by the Fire Protection Research Foundation (FPRF) has determined safe R290 charge limits for self-contained display cases in a range of settings.

For example, the study showed that a 1,000 g charge in an appliance in a big box grocery store is comparable in safety to a 150 g charge in a small commercial kitchen.

The study focused on the flammability hazards inherent in closed cases in commercial and retail kitchens. Its findings are significant because they indicate that it is safe to raise the charge limit of R290 for wider use in commercial refrigeration under certain conditions. Currently, the Environmental Protection Agency caps the charge limit for R290 in commercial appliances at 150 g.

The following R290 charges in various commercial settings were listed, each having the same risk factor as a 150 g charge in a small commercial kitchen:

- Up to 300 g in a 71 $m^3$ delicatessen or a 196 $m^3$ kitchen
- Up to 600 g in a 90 $m^3$ market
- Up to 1,000 g in a 1,023 $m^3$ big box grocery store

The driving force of the study was to assess the fire risk involved with larger charges of A3 (flammable) refrigerants to determine if they can be used in a wider range of applications. Larger allowable charge sizes equate to larger equipment that can run on R290, it was pointed out. Authors estimate that the charge limit for R290 will be raised in the near future.

In order to evaluate the risk posed by increasing the charge limit of R290, the study looked at both the probability of an event occurring and the possible consequences of such an event.

[24] Davis S.G. (2017). *Evaluation of the Fire Hazard of ASHRAE Class A3 Refrigerants in Commercial Refrigeration Applications.* Research Foundation - Research for the NFPA Mission. Last retrieved 13/09/18 at https://www.nfpa.org/-/media/Files/News-and-Research/Resources/Research-Foundation/Research-Foundation-reports/Hazardous-materials/RFA3refrigerantsGexcon.pdf

There were two main types of R290 leaks that were observed. The first was a high-pressure jet – a short duration, high momentum and low-charge leak -- where the R290 was diluted when the charge size and room volume were scaled properly. The ignition risk for this type of leak was centered on the location of the leak.

The next leak type resulted in the settling of heavier-than-air R290 at the ground level – a bigger leak with low momentum and larger charge. Without a condenser fan, flammable volumes were observed to accumulate at floor-level and pose an ignition risk.

Notably, both leak types were observed in test settings where there was no mitigating mechanical ventilation. With a condenser fan on in a properly scaled room, it's possible to mitigate risks so that the R290 mixes and does not reach flammable levels even at a 600 g charge.

A condenser fan, early detection system, and properly scaled room, authors explained, are amongst the key factors that will facilitate a safe increase of the R290 charge limit.

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**CASE STUDY 3.3.1: HYDROCARBON WATERLOOP SYSTEM IN BELGIAN CARREFOUR STORE [25] [26]**

**Summary: In September 2016, the first Carrefour Belgium R1270 store (200 $m^2$) was opened in Belgium.**

The 200 $m^2$ Carrefour Express convenience store in Laeken – a neighbourhood of Belgian capital Brussels – opened its doors in September 2016. It represents the first store of the French multinational using hydrocarbons and a water-loop system.

The store contains R1270-based cabinets provided by a major British manufacturer. Each of the store's eight cabinets was fitted with one or two self-contained, factory-sealed, and pre-charged refrigeration systems featuring a compressor, an evaporator and a water-plate condenser.

A hydraulic circuit connecting cabinets water-plate condensers, fitted with pumps and an external dry cooler, circulates a mixture of water and R1270 glycol through the store. Circulating the water mixture removes heat from the cabinets. The water itself is directly cooled down by means of a heat exchange with external air without using a chiller. Mixing the water with R1270 glycol stops the fluid from corroding the pipes and freezing when the temperature outside is cold.

As for the refrigerant charges, the store contains the following:

- 3 MT cabinets (3.75 m), each using 650 g of R1270
- 3 MT cabinets (2.5 m), each using 430 g of R1270
- 2 LT 3-doors cabinets (~2.3 m), each using 2x550 g of R1270

Therefore, the total charge of refrigerant is 5.44 kg. Systems' cooling capacity ranges between ~1.4 (3-doors LT cabinets) and ~2.2 (3.75 m MT cabinets).

[25] Williams A. (2016). *Carrefour Belgium opens its first propylene water-loop store*. Last retrieved 13/07/18 at http://hydrocarbons21.com/articles/7167/exclusive_carrefour_belgium_opens_its_first_propylene_water_loop_store
[26] Information received from Carrefour.

The refrigerant charge required a special design of the store. There are no electric sockets under or behind the cabinets. Instead, each cabinet is served by a socket positioned at a certain height (outside the potential explosive atmosphere that may form in case of R1270 leak). Proper and regular maintenance interventions contribute to the general safety of the store.

Amongst the standards followed when designing the systems, BS EN 378-2 (safety of refrigerating systems and heat pumps), EN 60079-10-2015 (explosives atmospheres), EN 60079-15-2015 (protection of electrical equipment) and EN 60335-1 (safety of household and similar electrical appliances).

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### CASE STUDY 3.3.2: WATER-COOLED HYDROCARBON PLUG-INS BY WAITROSE [27]

**Summary: Waitrose has chosen to use plug-in units with R290 or R1270, and as of summer 2018 has installed them in around 180 of its stores. Store sizes range from 280 m$^2$ to 3,700 m$^2$.**

The third-generation system that Waitrose has installed self-contained cabinets with a water-cooling loop connected to an external dry air cooler – reducing the power needed to cool the water.

Compared to the previous remote system running on HFC-404A, each converted store saves 7% of its electricity and 60% of its gas, since the waste heat from the cooling loop is used to provide space heating. This reduces operating costs by € 73,500 per store per year, and the capital cost of each new system saves the company around € 96,000. The hydrocarbon leakage rate is 2.9% and each store reduces total carbon emissions by around 700 t$CO_2$e per year from energy efficiency and reduced leakage. The system is also considered 99.6% reliable.

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### CASE STUDY 3.3.3: R290-COOLED SUPERMARKET IN BRAZIL [28]

**Summary: Switching from a remote R22 system to R290-based solution with hermetic reciprocating compressors delivered a 35% reduction in the total cost of ownership by reducing energy consumption by 37% and offering up to €200,000 in maintenance cost savings over a period of one year.**

For its 1,600 m$^2$ store, Mig Supermercados (a supermarket chain in Southern Brazil) decided to retrofit its refrigerated area with environmentally-friendly cabinets using R290.

Compared to the previously semi-hermetic system using R22 and an alternative using $CO_2$, the R290-based solution resulted in improving aesthetics of the store (attracting new clients), leading to environmentally-friendly results (approximately 97% of $CO_2$ emission reduction) and an increase in the merchandise area (compared to the previous reach-ins and islands without doors, with remote refrigeration). In terms of financial viability this system is also the most convenient one of the three (-18% and - 22% compared to the R22- and $CO_2$-based systems respectively), given its low maintenance and energy consumption costs (with a possible saving of €1500/month and 35% reduction of total cost of ownership). Considering only the

[27] Peters T. (2017). *Retail Refrigeration: Making the transition to clean cold*. Birmingham Energy Institute, University of Birmingham. Last retrieved 13/07/18 at https://www.birmingham.ac.uk/Documents/college-eps/energy/Publications/Retail-Refrigeration.pdf

[28] Zgliczynski M. (2018). *Embraco Plug n'Cool - A supermarket case study*. Presentation at ATMOsphere Australia 2018. Last retrieved 04/10/18 at http://www.atmo.org/media.presentation.php?id=1322

refrigeration system, the R290-based solution indeed consumes almost half (270 vs 425 kWh/day) the amount of the one using R22. The use of doors in the R290-based hermetic reciprocating technology (and absent in the R22 system) facilitates some of the energy savings.

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**CASE STUDY 3.3.4: ROLLING OUT R290 CHILLERS IN INDONESIA [29]**

**Summary: Large Indonesian pharmaceutical company PT Phapros installed and commissioned two R290 chillers at its production facility in Semarang, Central Java. The new R290 chillers have replaced old R134a chillers and are expected to significantly reduce the company's energy use.**

At the beginning of 2018 large Indonesian pharmaceutical company PT Phapros installed and commissioned two AICOOL R290 chillers, replacing two existing R134a units, at its production facility in Semarang, Central Java.

The two chillers each have a cooling capacity of 231.9 kW and each use around 30 kg of R290. The chillers are used to cool various rooms for drug production, storage and breeding of bacteria in PT Phapros' production building.

According to the company, the old R134a chillers used 545,387 kWh of electricity per year, costing the company around IDR 600 million (€ 36,155) per year in energy costs. The new R290 chillers are expected to use only 151,078 kWh per year, resulting in around IDR 160 million (€ 9,640) per year in energy costs.

Though the old R134a chillers were very old systems, with capacities that were significantly larger than needed, the reduction still translates to a cost saving of around IDR 440 million (€ 22,827) per year. The company estimates the payback period to be around two and a half years and its annual greenhouse gas emissions to be reduced by 356 $tCO_2$ per year.

The company considers the installation of natural-refrigerant systems to play a central role in a number of programmes the company is pursuing to achieve its sustainability goals.

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**CASE STUDY 3.3.5: R1270, EFFICIENT COOLING FOR FISH IN SCOTLAND**

**Summary: Europe's largest whitefish market benefits from hydrocarbon refrigeration system to cool fresh fish.**

Less than 30 kg of R1270 refrigerant is utilised to refrigerate 3,665 $m^2$ of floor area for the trading of fresh fish direct from fishing boats in the Scottish port of Peterhead. The newly built facility comprising an extensive trading area 250 m in length is chilled to +2°C using a 325 kW, five-circuit, SRS Frigadon air cooled hydrocarbon chiller. The stainless-steel cased unit has been designed to minimises refrigerant charge whilst at the same time ensuring the evaporators and condensers work at optimum conditions and incorporate various specialist safety features to ensure dispersion of any release, both during operation and service.

A low viscosity brine is utilised as a secondary fluid to maximise heat transfer whilst minimising pressure loses, intelligent pumps manage the flow the rate to match cooling

[29] Yoshimoto D. (2018). *Indonesian pharmaceutical giant installs R290 chillers*. Last retrieved 22/08/18 at http://hydrocarbons21.com/articles/8497/indonesian_pharmaceutical_giant_installs_r290_chillers

demand, delivering only the correct quantity of fluid required by the room coolers. This combination of measures ensures a very low energy input with rejected heat from the chiller also utilised to provide warmth to the occupied staff areas.

Natural convection heat exchangers are utilised within the chilled area, providing cooling with low air velocity to ensure the fish is presented and maintained with minimal dehydration whilst traded.

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**CASE STUDY 3.3.6: COLRUYT PROGRESSING TOWARDS 100% HYDROCARBONS [30]**

**Summary: Natural refrigerants are helping the Colruyt Group to save money and deliver its environmental targets, with the Belgian retailer moving to hydrocarbons for 100% of its in-supermarket cooling needs.**

Founded in 1925, the Colruyt Group is one of Belgium's biggest retailers, employing over 29,000 staff and boasting more than 500 shops.

In December 2014 the Colruyt Group adopted the official target of using 100% natural refrigerants for all its cooling needs. Choosing the right refrigerant, therefore, is crucial for meeting its sustainability target to become totally HFC-free.

Since the end of 2016, Colruyt is no longer building HFC cooling systems in its Colruyt, OKay and Bio-Plant stores. After considering which natural refrigerant would best match their needs, the group opted for hydrocarbons for in-store cooling.

The first hydrocarbon-based system was installed in Roeselare in 2013, with a 14 kg R290 condensing unit housed outside. This system still works fine and without any leakages. However, this concept is not adapted to less spacious sites and has no redundancy and any maintenance of a problem on the refrigerant circuit would mean closing the shop and emptying it from all refrigerated products.

Since 2015, Colruyt Group tested a new modular system with compact chillers with max. 2.5 kg of R290 or R1270 in four Bio-Planet stores.

From September 2016 Colruyt is implementing these systems in all new or renovated Colruyt, OKay and Bio-Planet stores. The first Colruyt stores were opened in Morlanwelz and Kortrijk in November 2015. The current blueprint is based on two or three small refrigerant circuits each with a maximum propene charge of 2.5 kg, and a secondary system that uses R1270 glycol to bring the cold to where it is needed.

With a refrigeration capacity of 30 to 50 kW, large supermarkets need to run two compact chillers. An extra chiller is always added redundantly, ready to step in should the other fail. Using a smaller refrigerant charge means they can be placed inside the store. More specifically, the individual refrigeration systems are put together thanks to the modular system of the chillers in use.

With natural refrigerants, the group's emissions of $CO_2$ are expected to lower by at least 10%.

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[30] Information received from Colruyt.

## 3.4 Heat pumps

Heat pumps in this report account for the systems that can provide heating, cooling and sanitary hot water for residential and light commercial use. The types of heat pumps taken into account for this section of the report are[31]:

*Air / exhaust air to water:* Air source heat pumps use the ambient energy in outside-air or exhaust-air for heating, cooling and preparation of hot water. They can be installed as compact units entirely inside or outside the house (so called mono-bloc). Split systems consist of one unit inside the building and one outside.

*Exhaust air heat pump (EAHP)* technology already started in Sweden in the early 90s. Exhaust air heat pumps use the air extracted from the bathrooms, utility rooms and kitchen for providing heating and domestic hot water and are in particular extremely appropriate for new constructions. Exhaust air concept perfectly suited the need of an efficient, robust and cheap heat pump dedicated to small new-built houses and apartments in multifamily buildings. However, it was needed to achieve higher water temperature in order to simplify the existing exhaust air product design to lower the cost while keeping the efficiency at a high level. R290 was the perfect candidate to replace traditional HFCs. Being EAHPs low capacity heat pumps, the refrigerant load is low enough so that even where using R290 the heat pumps can be installed indoors.

*Water to water:* Water source heat pumps use energy stored in ground, surface or sea water. The heat pump extracts heat from the water and makes it available for heating, cooling and preparation of hot water.

Heat pumps for residential use are more often smaller in capacity then those used in light-commercial applications, such as hotels, which can easily reach more than 100 kW. Nevertheless, smaller heat pumps can be used also for light-commercial applications (offices) and larger heat pumps can be used for a complex of residential buildings.

### 3.4.1 Market size of hydrocarbon-based heat pumps

Approximately 25 companies on the European market were identified to be offering R290-based residential and light-commercial heat pumps. Nevertheless the share of HC-based heat pumps in companies' product portfolios is still relatively small.

In addition, there is a wider variety of residential heat pump technology using R290 on the European market compared to 2016. Among the companies identified in the market research, one manufacturer produces ground source residential heat pumps using R290, 13 are manufacturing air-to-water R290-based residential HP, three are manufacturing brine-water heat pumps using R290 for residential application, and five manufacturers offer water source residential HP using R290.

Based on the data collected from heat pump manufacturers who answered the data collection survey, the estimated number of heat pumps with hydrocarbons today in Europe is between 200,000 - 220,000 units.

[31] EHPA (2018). What type of heat pump for what use?. European Heat Pump Association. Available at: http://www.ehpa.org/technology/what-type-of-hp-for-what-use/

### 3.4.2 Cost and energy efficiency

Indications about the initial cost, energy efficiency and life cycle cost shows a similar story as for commercial refrigeration. Both for residential and light-commercial applications, one third of respondents indicated that hydrocarbon heat pumps are slightly more expensive than their HFC counterparts, with the majority of the other respondents saying the costs are either considerably more expensive or on par. The higher initial cost is, however, offset by the energy efficiency gains of hydrocarbon refrigerant-based heat pumps, which the majority of respondents indicated to range between 6-25% more efficiency gains as compared to HFC systems. Energy efficiency has an impact on the operational costs, which as a consequence bring the life cycle costs down. According to respondents, life cycle costs of hydrocarbon refrigerant-based heat pumps are on par or slightly lower than HFC current technology. For 20% of respondents, life cycle costs are reported to be considerably lower.

**RESIDENTIAL HEAT PUMPS**

Table 3.4.1: (Survey question) How does the initial cost of the hydrocarbon-based units your organisation is using / providing compare to units using HFC refrigerants (current standard technology)? Percentages refer to percentage of respondents.

| Initial cost: Residential heat pumps | Europe | Rest of world | Worldwide |
|---|---|---|---|
| a) Considerably more expensive | 14.3% | 28.6% | 17.9% |
| b) Slightly more expensive | 33.3% | 42.9% | 35.7% |
| c) On par | 33.3% | 28.6% | 32.1% |
| d) Slightly less expensive | 14.3% | 0.0% | 10.7% |
| e) Considerably less expensive | 4.8% | 0.0% | 3.6% |
| **Grand total** | **100.0%** | **100.0%** | **100.0%** |

Table 3.4.2: (Survey question) What are the average energy efficiency gains of the hydrocarbon-based units your organisation is using / providing, compared to units using HFC refrigerants (current standard technology)? Percentages refer to percentage of respondents.

| Efficiency gains: Residential heat pumps | Europe | Rest of world | Worldwide |
|---|---|---|---|
| a) Hydrocarbon-based units are less energy efficient | 8.3% | 0.0% | 6.7% |

| | | | |
|---|---|---|---|
| b) 0 % | 12.5% | 0.0% | 10.0% |
| c) 1-5 % | 12.5% | 16.7% | 13.3% |
| d) 6-10 % | 33.3% | 33.3% | 33.3% |
| e) 11-25 % | 25.0% | 16.7% | 23.3% |
| f) 26-50 % | 8.3% | 33.3% | 13.3% |
| **Grand total** | **100.0%** | **100.0%** | **100.0%** |

Table 3.4.3: (Survey question) How does the life cycle cost of the hydrocarbon-based units your organisation is using / providing compare to units using HFC refrigerants (current standard technology)? Percentages refer to percentage of respondents.

| Life cycle cost: Residential heat pumps | Europe | Rest of world | Worldwide |
|---|---|---|---|
| a) Considerably higher | 0.0% | 22.2% | 6.7% |
| b) Slightly higher | 4.8% | 33.3% | 13.3% |
| c) On par | 42.9% | 22.2% | 36.7% |
| d) Slightly lower | 28.6% | 11.1% | 23.3% |
| e) Considerably lower | 23.8% | 11.1% | 20.0% |
| **Grand total** | **100.0%** | **100.0%** | **100.0%** |

## LIGHT COMMERCIAL HEAT PUMPS

Table 3.4.4: (Survey question) How does the initial cost of the hydrocarbon-based units your organisation is using / providing compare to units using HFC refrigerants (current standard technology)? Percentages refer to percentage of respondents.

| Initial cost: Light commercial heat pumps | Europe | Rest of world | Worldwide |
|---|---|---|---|
| a) Considerably more expensive | 28.6% | 16.7% | 26.8% |
| b) Slightly more expensive | 31.4% | 33.3% | 31.7% |
| c) On par | 31.4% | 16.7% | 29.3% |
| d) Slightly less expensive | 5.7% | 16.7% | 7.3% |
| e) Considerably less expensive | 2.9% | 16.7% | 4.9% |
| **Grand total** | **100.0%** | **100.0%** | **100.0%** |

Table 3.4.5: (Survey question) What are the average energy efficiency gains of the hydrocarbon-based units your organisation is using / providing, compared to units using HFC refrigerants (current standard technology)? Percentages refer to percentage of respondents.

| Efficiency gains: Light-commercial heat pumps | Europe | Rest of world | Worldwide |
|---|---|---|---|
| a) Hydrocarbon-based units are less energy efficient | 6.7% | 0.0% | 5.6% |
| b) 0 % | 10.0% | 0.0% | 8.3% |
| c) 1-5 % | 10.0% | 16.7% | 11.1% |
| d) 6-10 % | 46.7% | 0.0% | 38.9% |
| e) 11-25 % | 23.3% | 50.0% | 27.8% |
| f) 26-50 % | 3.3% | 33.3% | 8.3% |
| **Grand total** | **100.0%** | **100.0%** | **100.0%** |

Table 3.3.6: (Survey question) How does the life cycle cost of the hydrocarbon-based units your organisation is using / providing compare to units using HFC refrigerants (current standard technology)? Percentages refer to percentage of respondents.

| Life cycle cost: Light commercial heat pumps | Europe | Rest of world | Worldwide |
|---|---|---|---|
| a) Considerably higher | 2.9% | 30.0% | 9.1% |
| b) Slightly higher | 2.9% | 20.0% | 6.8% |
| c) On par | 32.4% | 30.0% | 31.8% |
| d) Slightly lower | 38.2% | 10.0% | 31.8% |
| e) Considerably lower | 23.5% | 10.0% | 20.5% |
| **Grand total** | **100.0%** | **100.0%** | **100.0%** |

**CASE STUDY 3.4.1: R290-COOLED WESTMINSTER ABBEY IN LONDON**[32]

**Summary: The Church House in Westminster Abbey, close to Houses in Parliament in London, has been using a R290-based chiller since 2007.**

Opened in 1940 by King George VI to commemorate Queen Victoria's golden jubilee, the Church House in Westminster Abbey in London has been served by a 600 kW air-cooled water chiller using R290 as refrigerant. This successful installation represented a milestone for the development of hydrocarbon-based chillers for air conditioning. It is estimated that the capital, installation and disruption costs are more than offset by the financial and environmental benefits of the new system.

For the same cooling output in kW (625), load factor percentage (50), cost of energy in £/KWh (0.063) and run hours (3,000), the hydrocarbon-based system proves to be better than the previous R134a chiller. The new one has a higher COP (4.15 vs 2.82), requires less power input in kW (150.6 vs 221.6) and consumes less energy on a yearly basis in KWh (225,900 vs 332,400).

In terms of economic viability, despite higher installation costs (€ 78.900 vs € 67.800), the new system is a convenient option in the long term. Its 10-years lifecycle cost leads to a € 64,880 saving (€ 240710 vs € 305,290): in percentage, this is a saving by 21.2%.

[32] Cox N. (n.d.). *The Use of Natural Refrigerants in Large AC Chillers.* Last retrieved 13/08/18 at https://ec.europa.eu/clima/sites/clima/files/docs/0007/earthcare_nat_refrig_large_ac_chillers_en.pdf

**CASE STUDY 3.4.2: R600a AT DANISH HOSPITAL** [33]

**Summary: R600a chillers replaced outdated R22 chillers and additional hydrocarbon-based equipment installed at the Aarhus University Hospital Skejby in Denmark.**

The first hydrocarbon chillers were already installed in 2003 and as the hospital has been gradually expanded additional hydrocarbon chillers have been installed.

The larger chiller system:

- Uses nine air-cooled R290 based chillers each with a cooling capacity of 250 kW, coefficient of performance (COP) of 4.5 and a total of about 210 kg R290.
- Uses a free-cooler with a capacity of 300 kW.
- The chillers deliver a 35% R1270 glycol/ water solution at 9°C and a return of 15°C.

On top of the nine chillers there are also some special chillers around on the site working at different temperature levels, bringing the total number of hydrocarbon chillers on site to 15.

Moreover the latest installation made in the context of the gradual expansion encompassed two heat pumps that were put into operation in November 2010, with:

- Hydrocarbon refrigerant R600a of a total of about 80 kg.
- A total heating capacity of about 450 kW and a cooling capacity of about 325 kW.
- The units are built as two independent circuits on one frame.

The new system combines the cooling system with the heating system, an approach that is still not widely used in most places in the world, despite the obvious intrinsic energy savings. However, due to increasing energy prices, customers have become more receptive to using new ways of thinking to save on their energy bills.

As a result, the new system offers better performance meaning energy savings, which also translates to $CO_2$ emissions savings.

With the hospital normally obliged to take the required heat from the district-heating network, the project involved talks with the local district heating company. In the winter period, the supply temperature of water is 80°C and in the summer it is supplied at 70°C. The return is 40°C. This requires the heat pumps to deliver water at 80°C and at the same time cool water.

Using hermetic design with no shaft seals or semi-welded heat exchangers, the Danish manufacturer has eliminated most flammability concerns of the hydrocarbon refrigerant. For the units installed outdoor with a secondary loop an efficient micro bubble separator is included as a result of which no gas will ever reach inside and the possibility of getting a flammable concentration is not present. Moreover, in case of a leak, all power to the unit is cut out and can only be restarted manually from the panel (remote reset not possible).

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[33] Lobnig S. (2012). *Experience with R600a heat pumps installed at Danish hospital*. Last retrieved 13/08/18 at http://hydrocarbons21.com/articles/experience_with_r600a_heat_pumps_installed_at_danish_hospital

**CASE STUDY 3.4.3: GREEN HEAT PUMPS FOR DUTCH FLATS [34]**

**Summary: The heat pumps of a new block of flats in Culemborg, Gelderland region, will use R290.**

In the town of Culemborg in the Netherlands, 300 houses are being demolished in four phases and replaced by 216 modern multi-family houses. The first house was completed at the end of 2013.

The requirement for the heating system was to heat as efficiently and environmentally friendly as possible and prepare hot water as well. Because of that, a total of 52 dual air/water heat pumps in five story complexes have been chosen to be installed outdoor. More will follow in the upcoming years.

In addition, each unit is equipped with a hydraulic module HMD 1 / RE. The energy gained from the air is distributed through a 100 liter tank for underfloor heating and a 200 liter tank for domestic hot water.

The total capacity is approximately 460 kW. Every single heat pump (7 kW heating capacity) has a charge size of 1.1 kg of refrigerant and a COP value of 3.8 at A2/W35. As for the costs of installation they vary depending on the peculiar feature of each installation, while maintenance costs for the 7 kW units are approximately 9,000 €.

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**CASE STUDY 3.4.4: R290 EXHAUST AIR HEAT PUMP SYSTEMS PROVIDE COST-EFFECTIVE AND RELIABLE HOME HEATING [35]**

NIBE's F470 contains 440 g of R290 and provides balanced ventilation, domestic hot water and 2.2 kW of heating. One major advantage of R290 compared to other HFC is that R290 provides high water temperature while keeping the efficiency high. The overall efficiency of F470 reaches $A^{++}$ and the system can heat the domestic hot water up to 70°C to prevent legionella without the help of any backup heater. F470 costs approximately 7,000€. F470 being an hermetically sealed product, the installation cost is the same as an electrical boiler. R290 being out of the F-Gas Regulation scope, there is no specific requirement in term of maintenance. These heat pumps found recently interesting application in Britain, amongst other countries.

**Summary 1: A brand new luxury apartment complex in West London has been fitted with a range of R290 exhaust air heat pump systems from NIBE – providing residents with a cost-effective, sustainable and dependable supply of heating, hot water and ventilation.**

Located directly opposite Ravenscourt Park on Goldhawk Road, in the desirable Hammersmith area of London, Parkside Place comprises 40 high-spec, one-, two- and three-bed homes. Tasked with ensuring the complex met Code for Sustainable Homes Level Four standards, developer Linden Homes needed to find a reliable solution to efficiently meet the properties' space heating and hot water needs, while simultaneously supplying sufficient ventilation for the well-insulated, new-build homes. Providing residents with optimum efficiency and a comfortable indoor environment – as well as a system that would be both economical and easy to use – were also key considerations for the project.

[34] Information received from Ait - Deutschland.
[35] Information received from NIBE.

Linden Homes opted for NIBE F470 exhaust air heat pump (EAHP) systems for each of the development's 23 single-level apartments. The remaining 16 split-level duplexes and one mews house were each fitted with an air source heat pump (ASHP) package system made up of an 8kW NIBE F2040 ASHP and a NIBE VVM320 combined water storage and controls unit.

With a strong focus on sustainability at the heart of the whole development, performance, efficiency and reliability were top priorities for us when it came to choosing the right heating systems for Parkside Place. Not only do the homes boast high levels of airtightness, they are also fitted with water-based underfloor heating throughout – making them ideally suited for heat pumps (which operate at similarly low flow temperatures). NIBE's F470 EAHPs were just right for the smaller, single-level apartments, particularly as they offer the added benefit of keeping the homes properly ventilated – which is crucial given how well-insulated they are.

**Summary 2: A South Wales developer has fitting eight properties with NIBE R290 exhaust air heat pump systems at its flagship house-building project.**

The systems were specified to provide cost-effective and reliable home heating and ventilation for the Great House Farm development on the outskirts of Cardiff. The new development's one-, two- and three-bedroom properties boast some of the most advanced sustainability measures of any UK housing project. As well as eight NIBE F470 EAHPs, the homes have been fitted with rainwater harvesting, green roofs, electric car charging points, extensive insulation and thermally treated windows throughout – achieving a Code for Sustainable Homes Level Four for building fabric alone.

When embarking on the project, developer LivEco was tasked with ensuring any improvements to the Grade-II listed farm buildings remained as sympathetic as possible to the original style – whilst also incorporating new features that would provide residents with optimum efficiency and comfort all year round. Having worked with NIBE products before, local architect Gillard Associates specified the F470 EAHPs to provide hot water and space heating, as well as an effective ventilation solution, given the development's high levels of air tightness.

The benefits of more sustainable house-building – both for residents and for the wider local community – are undeniable. Great House Farm was built to provide lower impact living and reduced bills at an attractive price bracket, and the NIBE EAHPs are an important part of this.

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### CASE STUDY 3.4.5: EUROPEAN PROJECT DEVELOPS GREEN HEAT PUMP [36]

**Summary: The EU-funded (FP7) GreenHP project investigated a new highly efficient heating system based on high-capacity air/water heat pumps for residential and commercial applications.**

Between 2012 and 2016, nine partners of the GreenHP project gathered their efforts to develop an innovative heat pump system. The prototype to be presented at the end of the project lifetime was supposed to be more energy efficient and green than the state-of-the-art heat pumps on the market in 2012.

The 30 kW lab-scale air/water HP prototype uses R290 as refrigerant and presents a better coefficient of performance (COP) - 3 vs 2.5. Although in terms of indirect emissions R290 and other low-GWP HFCs present similar figures, R290 was chosen considering the possible limitations on the use of chemical refrigerants as well as its very low GWP. The result in terms

[36] GreenHP (2016). *Final project report*. Last retrieved 04/09/18 at http://www.greenhp.eu/deliverables/public-deliverables/?eID=dam_frontend_push&docID=3055

of $CO_2$ emissions is remarkable: in terms of g $CO_2$/kWh usable energy, the prototype has a value of 187 (vs 294 of mainstream HFC models). In terms of g refrigerant/kW heating the prototype shows a value (65) much lower than the state-of-the-art (HFC) HPs in 2012 (200-500).

Behind all these remarkable results, there are some important technical novelties. For example the evaporator constructed with multi-port extruded tubes and equipped with a novel bionic refrigerant distributor significantly minimises the refrigerant charge and increases the heat exchangers' efficiency.

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### CASE STUDY 3.4.6: A SUSTAINABLE HOTEL THANKS TO HYDROCARBONS [37]

**Summary: The Corbie Ring Hotel in Belgium, which officially opened its doors in February 2018, opted for the TripleAqua – a complete heating and cooling system that also stores energy – thanks to its efficiency and environmental credentials.**

The Corbie Ring Hotel in the Belgian town of Lommel is arguably the most sustainable hotel in Belgium. During construction of the hotel the owner opted to install the TripleAqua: an energy-efficient heat pump employing the natural refrigerant R290.

According to the calculations of a local HVAC contractor, the current setup was the best option, as space heating and cooling is generally responsible for the majority of a building's energy consumption.

It also had the highest payback for the end-user and was the most environmentally friendly solution.

Compared to other two recently-built hotels of the same brand, this hydrocarbon-based system is 50% more efficient.

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[37] McLaughlin C. (2018). *A sustainable hotel, thanks to hydrocarbons*. Last retrieved 30/07/18 at http://hydrocarbons21.com/articles/8440/a_sustainable_hotel_thanks_to_hydrocarbons

## 3.5 Air conditioning

Air conditioning systems examined in this report account for systems that can provide space cooling or heating for residential and light-commercial use. The types of air conditioning systems taken into account are:

*Portable room AC:* A portable room air conditioner is a compact unit that sits entirely indoors and can be used to cool or heat a room.

*Split room AC:* A split room air conditioner is a system which the compressor and condenser sits outside (outdoor unit), whereas the evaporator and expansion valve are inside the room (indoor unit). These types of systems exist in both single split and multi split varieties. The difference between the two is the outdoor unit of multi split systems is attached to more than one indoor unit, which are positioned in different rooms. In addition to systems that can provide only cooling, inverter type split room AC units can provide both cooling and heating.

*Air to air heat pumps:* Air source heat pumps absorb heat from the outside air. These systems produce warm air which is circulated by fans to heat spaces. Reverse cycle air to air heat pumps can also be used for space cooling.

### 3.5.1 Market size of hydrocarbon-based AC

The uptake of portable R290-based ACs is increasing in Europe with a growing number of companies offering this type of technology or planning to before the ban on HFCs with GWP > 150 under the F-Gas Regulation comes into effect. Eight companies were identified that manufacture this type of technology or plan to start in 2018. Based on the responses from companies who answered the data collection survey, the estimated number of portable ACs with hydrocarbons today in Europe is above 200,000 units. According to respondents, R290 is expected to take over the entire portable AC market in the next two years.

The market is still slow for small split type systems. R290 split AC units are not currently being sold in the European market. While several Chinese manufacturers and one Indian manufacturer have completed conversion of production lines, commercialised and certified their R290 products, the demand for this equipment in Europe is not high enough to bring it to the market. Indicatively, the Indian market currently counts more than 600,000 R290 split ACs sold domestically. The Chinese market on the other hand counts approximately 10,000 R290 split ACs sold. The actual production capacity of R290 split AC units is several millions due to the converted production lines of major manufacturers.

### 3.5.2 Cost and energy efficiency

When it comes to initial costs, for both residential and light commercial use, close to 50% of respondents indicated that hydrocarbon refrigerant-based systems are slightly more expensive than current HFC-based technology. In terms of efficiency, close to one third of respondents indicated that for residential applications hydrocarbon-based units have 6-10% more efficiency gains compared to units using HFC refrigerants. For light-commercial applications close to 60% of respondents indicated that hydrocarbon based units are between 1-10% more energy efficient. Lower energy consumption and maintenance costs have as a consequence for the life cycle cost to drop, with close to 60% of respondents indicating that the life cycle cost of hydrocarbon-based air conditioning systems is on par or slightly lower than current HFC technology. Industry representatives are certain that with an increased mass production of hydrocarbon-based units, costs will drop even more in the long-term.

### RESIDENTIAL AIR CONDITIONING

Table 3.5.1: (Survey question) How does the initial cost of hydrocarbon-based units your organisation is using / providing compare to units using HFC refrigerants (current standard technology)? Percentages refer to percentage of respondents.

| Initial cost: Residential air conditioning | Europe | Rest of world | Worldwide |
|---|---|---|---|
| a) Considerably more expensive | 11.1% | 27.3% | 15.8% |
| b) Slightly more expensive | 48.1% | 45.5% | 47.4% |
| c) On par | 25.9% | 27.3% | 26.3% |
| d) Slightly less expensive | 7.4% | 0.0% | 5.3% |
| e) Considerably less expensive | 7.4% | 0.0% | 5.3% |
| **Grand total** | **100.0%** | **100.0%** | **100.0%** |

Table 3.5.2: (Survey question) What are the average energy efficiency gains of the hydrocarbon-based units your organisation is using / providing, compared to units using HFC refrigerants (current standard technology)? Percentages refer to percentage of respondents.

| Efficiency gains: Residential air conditioning | Europe | Rest of world | Worldwide |
|---|---|---|---|
| a) Hydrocarbon-based units are less energy efficient | 6.7% | 0.0% | 4.9% |
| b) 0 % | 20.0% | 9.1% | 17.1% |
| c) 1-5 % | 23.3% | 9.1% | 19.5% |
| d) 6-10 % | 26.7% | 45.5% | 31.7% |
| e) 11-25 % | 20.0% | 9.1% | 17.1% |
| f) 26-50 % | 0.0% | 27.3% | 7.3% |
| g) More than 50 % | 3.3% | 0.0% | 2.4% |

| | | | |
|---|---|---|---|
| **Grand total** | **100.0%** | **100.0%** | **100.0%** |

Table 3.5.3: (Survey question) How does the life cycle cost of the hydrocarbon-based units your organisation is using / providing compare to units using HFC refrigerants (current standard technology)? Percentages refer to percentage of respondents.

| Life cycle cost: Residential air conditioning | Europe | Rest of world | Worldwide |
|---|---|---|---|
| a) Considerably higher | 3.8% | 8.3% | 5.3% |
| b) Slightly higher | 3.8% | 58.3% | 21.1% |
| c) On par | 34.6% | 16.7% | 28.9% |
| d) Slightly lower | 34.6% | 16.7% | 28.9% |
| e) Considerably lower | 23.1% | 0.0% | 15.8% |
| **Grand total** | **100.0%** | **100.0%** | **100.0%** |

**LIGHT COMMERCIAL AIR CONDITIONING**

Table 3.5.4: (Survey question) How does the initial cost of the hydrocarbon-based units your organisation is using / providing compare to units using HFC refrigerants (current standard technology)? Percentages refer to percentage of respondents.

| Initial cost: Light commercial air conditioning | Europe | Rest of world | Worldwide |
|---|---|---|---|
| a) Considerably more expensive | 15.2% | 38.5% | 21.7% |
| b) Slightly more expensive | 51.5% | 30.8% | 45.7% |
| c) On par | 21.2% | 23.1% | 21.7% |
| d) Slightly less expensive | 3.0% | 7.7% | 4.3% |
| e) Considerably less expensive | 9.1% | 0.0% | 6.5% |
| **Grand total** | **100.0%** | **100.0%** | **100.0%** |

Table 3.5.5: (Survey question) What are the average energy efficiency gains of the hydrocarbon-based units your organisation is using / providing, compared to units using HFC refrigerants (current standard technology)? Percentages refer to percentage of respondents.

| Efficiency gains: Light commercial air conditioning | Europe | Rest of world | Worldwide |
|---|---|---|---|
| a) Hydrocarbon-based units are less energy efficient | 6.9% | 0.0% | 5.1% |
| b) 0 % | 6.9% | 0.0% | 5.1% |
| c) 1-5 % | 31.0% | 20.0% | 28.2% |
| d) 6-10 % | 31.0% | 30.0% | 30.8% |
| e) 11-25 % | 17.2% | 20.0% | 17.9% |
| f) 26-50 % | 3.4% | 30.0% | 10.3% |
| g) More than 50 % | 3.4% | 0.0% | 2.6% |
| **Grand total** | **100.0%** | **100.0%** | **100.0%** |

Table 3.5.6: (Survey question) How does the life cycle cost of the hydrocarbon-based units your organisation is using / providing compare to units using HFC refrigerants (current standard technology)? Percentages refer to percentage of respondents.

| Life cycle cost: Light commercial air conditioning | Europe | Rest of world | Worldwide |
|---|---|---|---|
| a) Considerably higher | 6.3% | 15.4% | 8.9% |
| b) Slightly higher | 3.1% | 30.8% | 11.1% |
| c) On par | 31.3% | 23.1% | 28.9% |
| d) Slightly lower | 31.3% | 15.4% | 26.7% |
| e) Considerably lower | 28.1% | 15.4% | 24.4% |
| **Grand total** | **100.0%** | **100.0%** | **100.0%** |

### CASE STUDY 3.5.1: DEMONSTRATION PROJECT IN CHINA ON HYDROCARBON RAC UNITS[38]

**Summary: In a project (2008-13) supported by both the German and Chinese Ministries for the Environment, R290 was used by a Chinese manufacturer as a refrigerant on its production line for room AC. The experiences was shared with other companies in the sector and contributed to the global dissemination of the technology.**

The demonstration project aimed to study the production line for room air conditioners on a trial basis using hydrocarbons, and to identify the conditions needed for a successful launch of climate-friendly models onto the market. These models were adapted to comply with European safety and energy efficiency criteria.

Training courses were provided for production and service technicians to guarantee the safety of the operations when handling that flammable refrigerant. Teaching and information materials for technicians on the maintenance of air conditioners using hydrocarbon technology were prepared, in order to reduce the risk of accidents occurring with the still unfamiliar, flammable hydrocarbon refrigerants.

Company GREE installed the production line for room air conditioners, and TÜV SÜD, a German technical services organisation, certified it. Prototypes using R290 were developed and awarded the CE marking and certification by the VDE (Verband der Elektrotechnik Elektronik Informationstechnik e.V.), the German Association for Electrical, Electronic and Information Technologies.

Other Chinese manufacturers (Haier, TCL) showed major interest in the technology, and were equipped with modern filling stations for hydrocarbons meeting the European safety standards.

### CASE STUDY 3.5.2: NEW PATHWAYS FOR HYDROCARBONS IN INDIA [39] [40] [41]

**Summary: Over the last few years a significant growth in domestic sales of R290 room air conditioning units took place in India .**

Godrej was the first and only Indian company to shift to hydrocarbon-based refrigerant in refrigerators, developing its first R600-based product in 2000. In 2012 the company, thanks to a collaboration with German development agency GIZ and the Indian government, presented ACs using R290, chosen due to its high efficiency and minimal environmental impact. It became the first company worldwide producing HC-based AC.

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[38] GIZ. *Manufacture of room air conditioners using hydrocarbons as a replacement for halogenated refrigerants*. Last retrieved 13/07/18 at https://www.giz.de/en/worldwide/16676.html

[39] Ranson J. (2015). *Godrej forging new pathways for hydrocarbons in India and beyond*. Last retrieved 13/07/18 at http://hydrocarbons21.com/articles/6286/godrej_forging_new_pathways_for_hydrocarbons_in_india_and_beyond

[40] Rajadhaksha D. et al. (2015). *The first 100 000 HC-290 split air conditioners in India*. International Journal of Refrigeration, 60(2015), 289-296.

[41] Yoshimoto D. (2018). *Godrej plans for increased R290 RAC sales in India over next few years*. Last retrieved 13/08/18 at http://hydrocarbons21.com/articles/8306/godrej_plans_for_increased_r290_rac_sales_in_india_over_next_few_years

Currently the company is producing both fixed and variable (inverter) speed AC systems. One 1T 8-Star inverter model in particular has a remarkable ISEER value of 6.15 (while the EER of traditional systems using R22 and R410A is 3.5), leading then to important energy savings. Other 1T, 1.5T and 2T models have 3-, 4- and 5-Star ratings and lower ISEER (ranging however between 3.7 and 5.2).

In developing these products, the company had to study charge minimisation, performance optimisation and integration of safety features. The training of field technicians represents another key aspect to ensure the proper functioning and maintenance of these systems: more than 4,500 technicians were trained. Godrej upgraded its manufacturing facility to incorporate additional safety alarms and procedures for dealing with flammable refrigerants.

The company runs a quality database to keep track of complaints and faults. The main problem is leakage, which as of 2015 had happened only in less than 500 units (thus in less than the 0.5% of the units sold by that time). The annual leakage rate is considered to be extremely low, and in any case much lower (even by 10 times in certain cases) than those of competing HFC units. In terms of flammability safety, in a small number of cases the installation exceeded the maximum limit by a marginal amount: nevertheless in these cases the releasable refrigerant charge was still within the prescribed limits. As a result, the risk assessment analysis showed that the risk associated with such cases is still significantly less than negligible.

Besides India, the company has important market shares in Nepal, Maldives, Grenada, Bhutan, Philippines, Costa Rica and Thailand, selling in total over 600,000 RACs.

Currently in India hydrocarbon charges are effectively limited to 350 grams. A higher amount would pave the way to a broader adoption of natural refrigerants.

Given the lack of national standards for hydrocarbons in India, Godrej developed its R290 technology in collaboration with German development agency GIZ and the Indian government. Nonetheless, reference was made to European standards with regard to safety requirements. Systems using hydrocarbons generally can achieve a high level of efficiency (in terms of COP) across the range of competing products. Amongst the innovations that led to this result, an increased compressor displacement by about 10% and the optimisation of the condenser design as well as of capillary tube and charge amount.

# CHAPTER 4: MARKET POTENTIAL FOR HYDROCARBON-BASED HVAC&R EQUIPMENT

## 4.1 Plans to start working with hydrocarbons

Out of 82 respondents to the survey who currently are not working with hydrocarbons, more than half plan to start working in the future. The majority of them expect to start working with hydrocarbons somewhere between 2019-2020. When asked about the drivers in their future plans, "Compliance with current / future legislation" ranked highest with a score of 4 out of 5. "Environmental impact (direct and indirect emissions)" is following closely with a score of 3.8 out of 5.

According to manufacturers and end-users, F-gas legislation in Europe is playing an important role in driving the switch towards refrigerants with lower global warming potential. As HFCs are becoming increasingly expensive industry is looking at other options that are future-proof with respect to regulatory measures. Hydrocarbons in this case are widely accessible and cheap compared to synthetics.

Image 4.1.1: (Survey question) Are you planning to use / work with hydrocarbons in the future? Segmented per region group. Percentages refer to percentage of respondents.

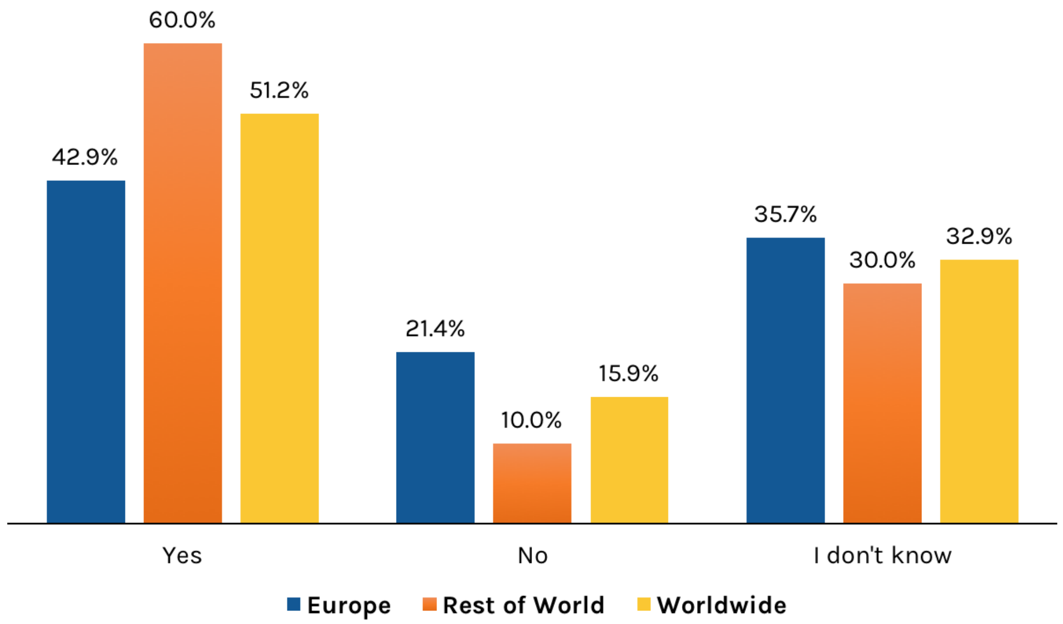


Image 4.1.2: (Survey question) When are you planning to start providing / using products with hydrocarbons? Segmented per region group. Percentages refer to percentage of respondents.

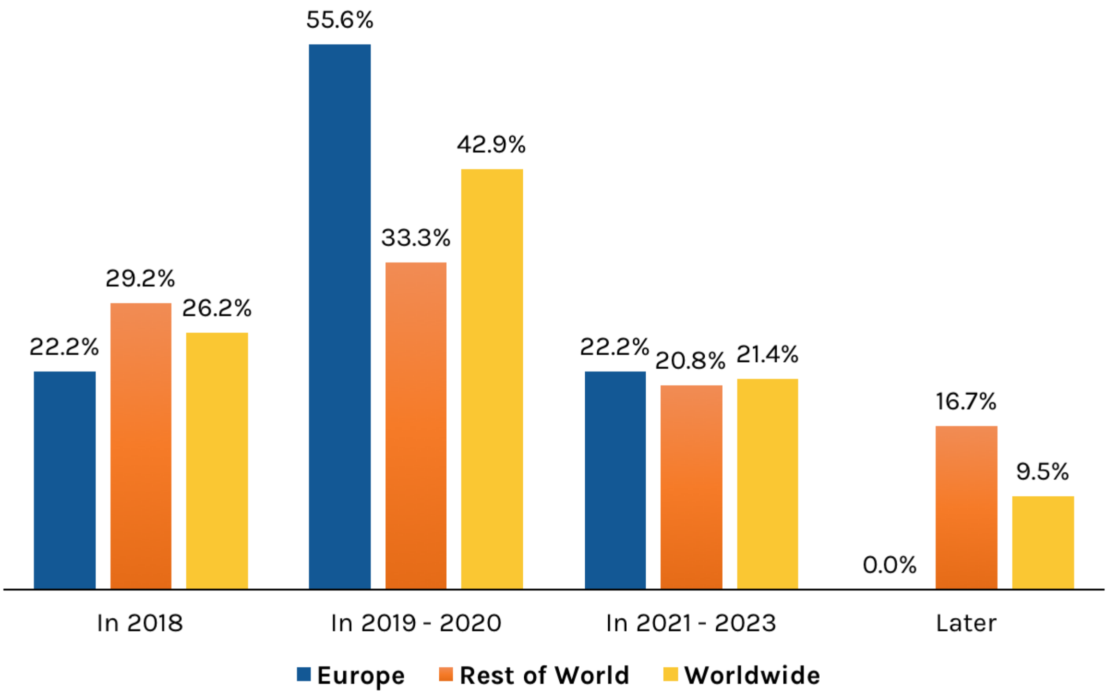



Table 4.1.1: (Survey question) What are the main drivers for your organisation to start providing / using products with hydrocarbons? Segmented per region. Scores from 1 (weaker) to 5 (stronger)

| Drivers | Europe | Rest of world | Worldwide |
|---|---|---|---|
| Driver: Energy efficiency gains | 2.7 | 3.4 | 3.1 |
| Driver: Simple design and manufacturing process | 1.6 | 2.4 | 2.1 |
| Driver: Improved design features (forced airflow, leak tightness, shut-off valves, pump down cycles etc.) can minimise risk of the higher flammable refrigerant charge | 1.4 | 2.7 | 2.2 |
| Driver: Simple repair and maintenance needs | 1.3 | 2.7 | 2.2 |
| Driver: Capital cost (initial investment) | 2.2 | 3.2 | 2.8 |

| | | | |
|---|---|---|---|
| Driver: Return on investment (life cycle cost) | 1.8 | 3.2 | 2.6 |
| Driver: Environmental impact (direct and indirect emissions) | 3.5 | 4.1 | 3.8 |
| Driver: Customer demand | 2.7 | 2.7 | 2.7 |
| Driver: Availability & supply | 3.3 | 3.0 | 3.1 |
| Driver: Compliance with current / future legislation | 4.2 | 3.9 | 4.0 |
| Driver: Available financial incentives | 2.5 | 2.4 | 2.4 |

## 4.2 Impact of standards

The ongoing revision of standards for an increase of hydrocarbon charge limits will play an critical role in the future uptake of hydrocarbon refrigerants in the HVAC&R sector. The current charge limits are prohibitive and obstructive for hydrocarbons. A potential update of safety standards to increase charge limits for flammable refrigerants has the potential to clear the path for hydrocarbons so that they can reach higher capacities more efficiently and at lower costs, thus serving a larger part of the market.

In order to make an assessment of the potential impact of the standards in the market, stakeholders currently working with hydrocarbons were asked what would be the expected percentage of their organisations' products related to hydrocarbon refrigerants by 2020 and by 2023 under two scenarios:

1. If standards allow higher charges;

2. If standards do not allow higher charges.

For plug-in units in commercial refrigeration, close to 65% of respondents indicated that their products related to hydrocarbons will exceed 50% of their entire product portfolio by 2023 if standards allow higher charges. If standards do not allow for higher charges, 46% of respondents indicated that hydrocarbon refrigerant-based products will exceed 50% of their entire product portfolio. In addition, the increase from 2020 to 2023 will be of larger impact if standards allowing higher charges are in place. Moreover, more than 50% of respondents indicated that their products related to hydrocarbons will reach 100% of their entire product portfolio by 2023 if standards allow higher charges, as compared to 30% respondents claiming the same in the case that standards will not allow higher charges. What emerges from this is that a large proportion of the market is planning to up their production of HC-based products, but with timely revision of standards this could happen for broader scale of products.

In the case of remote units in commercial refrigeration if standards allow higher hydrocarbon charges close to 45% of respondents indicated that their products related to hydrocarbons will exceed 50% of their entire product portfolio by 2023, with the percentage being less than 30% of respondents if standards do not allow higher charges. Interestingly, in the second scenario the percentage of respondents does show an increase from 2018 to 2020, but then slightly starts to decrease until 2023, showing that the lack of revised standards would have a negative long-term impact in the evolution of hydrocarbons refrigerant-based remote units for commercial refrigeration.

A significant number of respondents indicated that their products related to hydrocarbons will exceed 50% of their entire product portfolio by 2023 in case of residential air conditioning and heat pumps (more than 60% of respondents). Under the second scenario the percentage of respondents is at 37%. In the case of light-commercial applications for air conditioning and heat pumps, a significant negative impact can be seen if standards do not allow for higher charges, with only 15% of respondents indicating that hydrocarbon related products would exceed 50% of their entire product portfolio by 2023. On the other hand, if standards allow for higher charges 37% of respondents indicate that they will exceed 50% of their product portfolio.

The results of the survey verify that applications and systems which require a higher capacity (remote units for commercial refrigeration, air conditioning and heat pumps for light-commercial) are more sensitive to the refrigerant charge barriers for hydrocarbons and will face a stronger negative impact in their long-term uptake, if charge limits are not increased.

Overall, when aggregating the responses for all types of systems and plotting them in histograms based on the range of percentage share of hydrocarbon products in companies' product portfolios, it is clear that a change in the standards for charge limits will enhance a faster and larger uptake of hydrocarbon products by companies.

Stakeholders working with all types of applications indicated that without uniform standards embedded into national regulations, they cannot design products and scale their production to cover a uniform demand from various regions of the market. Creating custom design and configurations of products due to different national legislations on charge limits increases the cost and complexity of the manufacturing and distribution process.

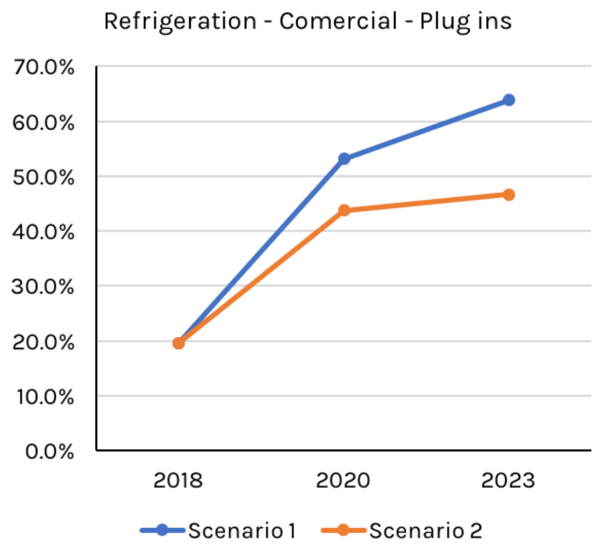
For some applications an increase in the uptake of hydrocarbons will happen, however, to a lower extent and at much slower pace. It is evident that standards for higher charges have the potential to remove barriers and restrictions and allow stakeholders to transition faster and without uncertainty to hydrocarbon refrigerants.

Image 4.2.1: (Survey question) Do you expect the share of your organisation's product portfolio related to hydrocarbons to exceed 50% by 2020 and by 2023, under the following two scenarios:

***Scenario 1)*** If standards allow higher charges;

***Scenario 2)*** If standards do not allow higher charges?

***Vertical axis*** indicates the percentage of respondents responding yes.



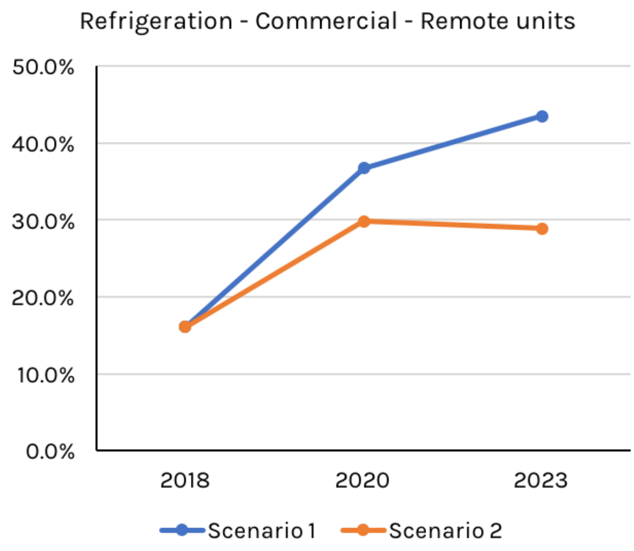
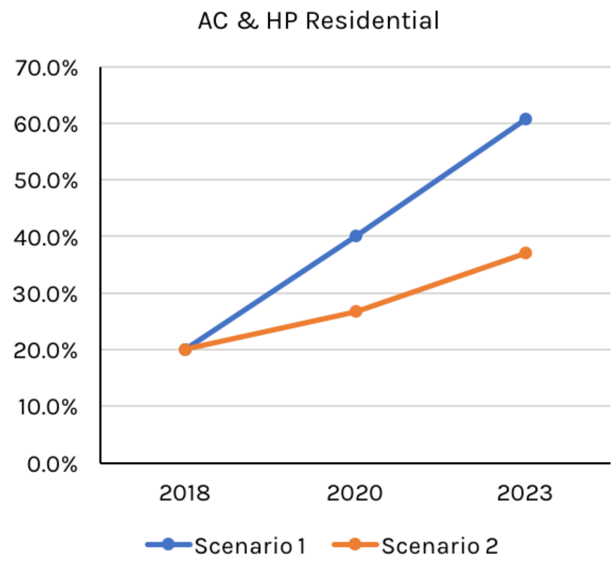




Image 4.2.2: (Survey question) Do you expect the share of your organisation's product portfolio related to hydrocarbons to exceed 50% by 2020 and by 2023, under the following two scenarios:

***Scenario 1)*** If standards allow higher charges;

***Scenario 2)*** If standards do not allow higher charges?

***Vertical axis*** indicates the percentage of respondents responding yes.



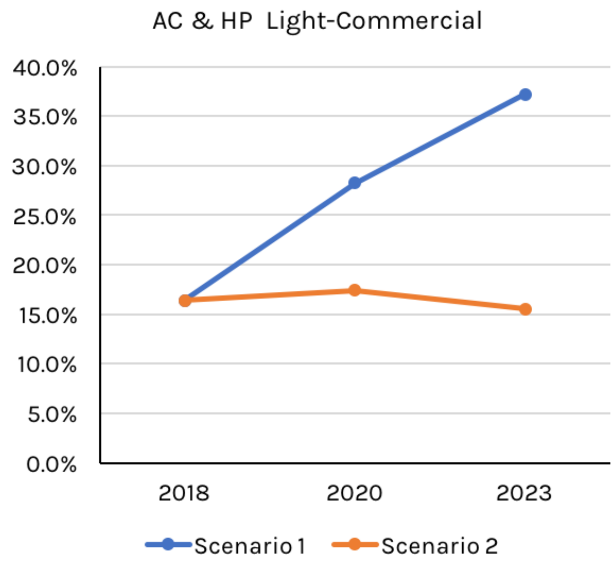



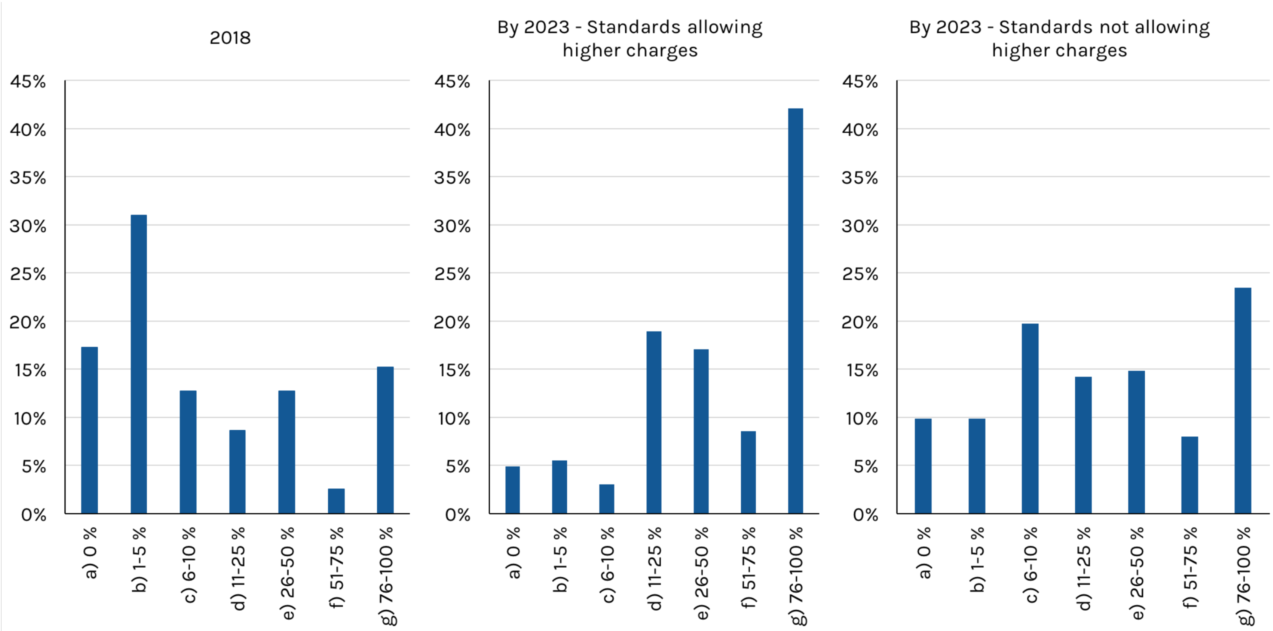
Image 4.2.3: (Survey question) What is the current percentage of your organisation's products[42] related to hydrocarbon refrigerants (left graph), and the expected percentage by 2023 under two scenarios:

Scenario 1: (Middle graph) If standards allow higher charges

Scenario 2: (Right graph) If standards do not allow higher charges

Vertical axis indicates the percentage of respondents

Horizontal axis indicates the shares of products related to hydrocarbon refrigerants in ranges.




## 4.3 Expectations, perception & acceptance of higher hydrocarbon charges

Key industry representatives expect a change in charge limits to happen in the next one or two years. For those that support the proliferation of hydrocarbon-based refrigeration equipment the update of the current standards represents a major game-changer that will allow hydrocarbons to become more competitive in the market and considerably increase the market share.

The key element to make higher hydrocarbon charges a success in the market, based on interviews from industry representatives, is for the change to be uniform and formally approved at the EU level as well as for it to be integrated into building codes. It is important for manufacturing companies to be able to industrialise the process of producing new products with higher hydrocarbon charges.

One additional element to make higher hydrocarbon charges a success, is to raise awareness and share information about the safety of products. Some end-users are concerned that higher charges are dangerous for their premises, and could even lead to explosions. It is important for

[42] In this graph the responses related to all types of products mentioned in more detail in this report are aggregated. This allows to show an aggregated general trend and impact.

end-users, especially the large market players, to understand that products with higher hydrocarbon charges can be designed and produced with a negligible flammability risk and at a similar level of other non-HC products, otherwise they would not accept these solutions in the market.

Among others, it is important to train technicians to ensure they are able to safely install and handle equipment containing higher hydrocarbon charges. Even though hydrocarbon based systems are not as complex as for example those designed to work with $CO_2$, targeted training should eliminate the fear that refrigeration professionals might have regarding hydrocarbons. Introducing hydrocarbons manipulation and technology in professional schools for technicians, as well as introduction of mandatory certification are options to achieve these goals.

For several manufacturing companies contacted for interviews, an increase of the charges is welcomed and seen with an open mind as a business opportunity. Companies already working with HCs do not have a problem to work with higher HC charges if this is officially allowed at the EU level (e.g. formally adopted within EN standards). They are convinced that this will have a positive impact for the penetration of hydrocarbons in the market.

According to the online survey, a significant majority of respondents, approximately 85%, claims they would not have an issue to work with higher hydrocarbon charges. When asked up to what charge their organization would be comfortable to work with, the majority (62%) indicated they could work with any charge as long as safety measures are properly taken care of. An additional 32% of respondents indicated that they would be willing to work with hydrocarbon charges up to 500g.

For this group of respondents all safety issues and any potential malfunctions can be solved by good combination of mitigation measures including intuitive control systems, a thorough risk assessment, good quality components, and skilled technicians to handle and maintain the systems.

These trends indicate that once approved, higher HCs charge limits will not take long to be incorporated in the market.

Image 4.3.1: (Survey Question) Would your organisation be willing to work with higher hydrocarbon charges (provided relevant standards are revised to allow this)? Segmented per region. Percentages refer to percentage of respondents.

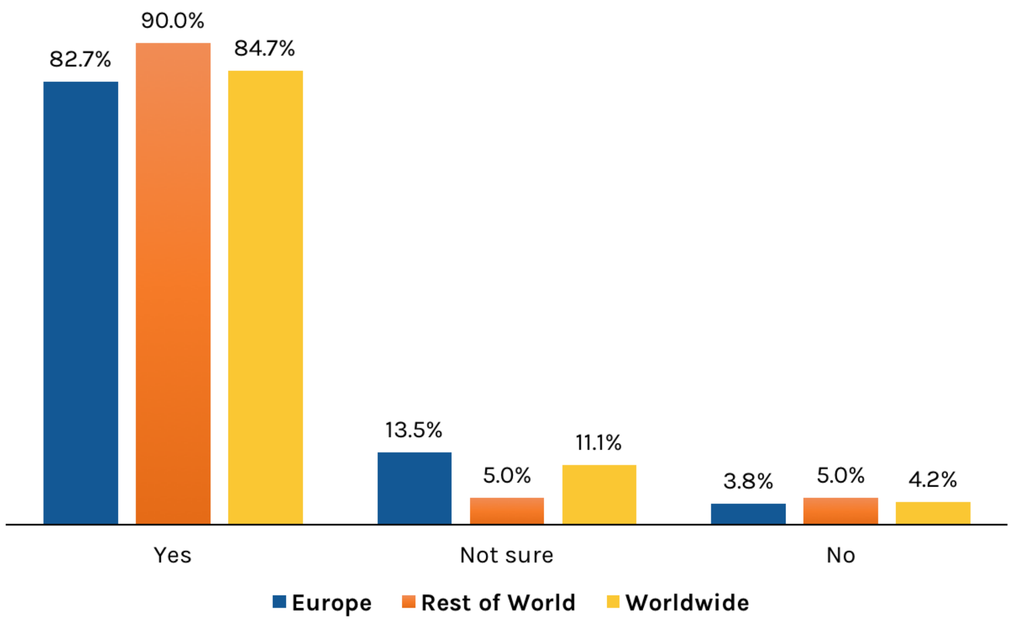
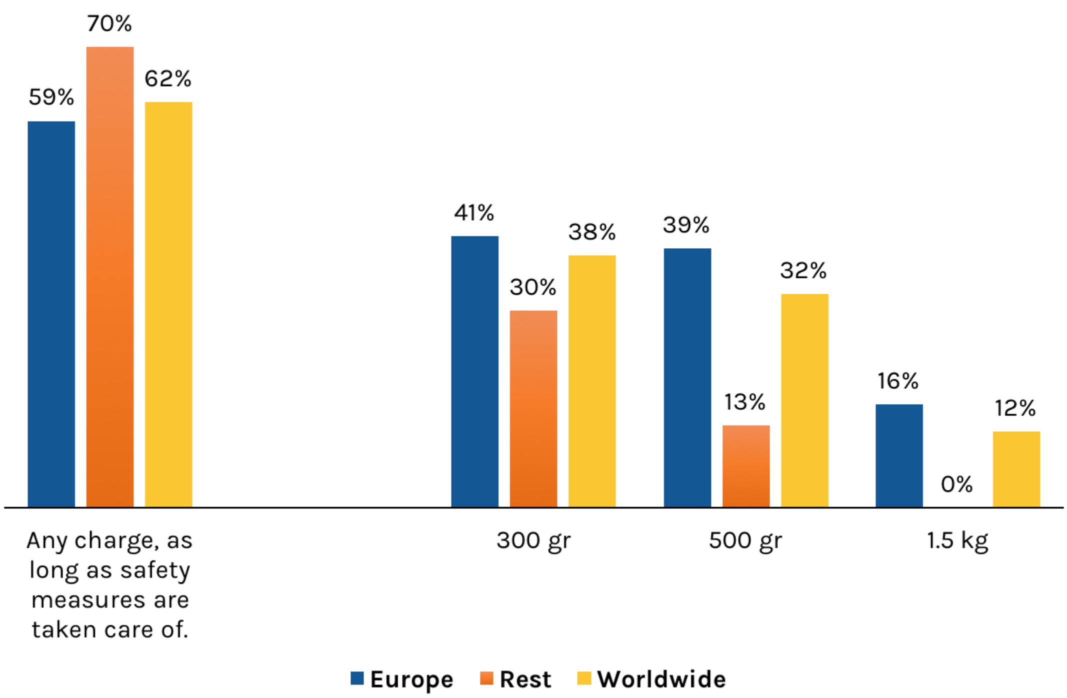



Image 4.3.2: (Survey Question) Up to what charge limit would your organisation be comfortable to work with? Segmented per region. Percentages refer to percentage of respondents.



## 4.4 Mitigation measures

To support increasing the allowable refrigerant charge a series of mitigation measures can be implemented to offset potential risk of greater charge sizes and therefore support the utilisation of hydrocarbons in a far wider amount of systems applying European and international safety standards.

The following mitigation measures are explored in greater detail below:

- Improved system tightness
- Systems with integral airflow
- Charge leak test method
- Housing design
- Sources of ignition test method

### 4.4.1 Improved system tightness

Allowable charge limits are built on the assumption of a 'catastrophic leak', in which the charge is released in a period of extremely short duration in the case of a leak. Due to the lack of time necessary for the refrigerant to dilute in the surrounding air, the system charge size must be limited to avoid the prohibited flammability concentrations from being easily reached.

Using a combination of the below tightness measures, testing has demonstrated that between 2 - 3 times more refrigerant can leak before the prohibited lower flammability limit is reached:

- The possibility of external mechanical damage within equipment housing is prevented
- Fretting and chaffing of components cannot occur
- The configuration of equipment piping prevents negatively impactful resonances
- The risk of damage to components from fans or build up ice is eliminated

To avoid assuming a 'catastrophic leak' in all scenarios, these system tightness measures could be implemented in current safety standards and substantially reduce the probability of such a leak. With an assumption that the leak is slower due to system tightness, a greater refrigerant charge could be allowed due to the greater amount of mixing in the air and thus lower probability of reaching the lower flammability limit.

### 4.4.2 Systems with integral airflow

In general, refrigeration and air conditioning equipment use fans to disperse heated or cooled air away from the system or appliance. Current safety standards do not account for airflow of HCs from using fans, and instead assume that any released refrigerant charge will only mix with surrounding air due to natural buoyancy forces.

If these fans used by refrigeration and air conditioning equipment are continuous or are triggered by a leak sensor, the airflow generated should be accounted for in the dilution of a leaked refrigerant. As a result, a greater refrigerant charge should be allowed for a given room size.

### 4.4.3 Charge leak test method

Allowable charge limits are also built on the assumption that the entire refrigerant charge is released in the case of a leak. However, testing has demonstrated that approximately 3-15% of the total charge will remain in the system at atmospheric pressure after a leak, depending on the system size and configuration, leak location and operating conditions. Moreover, the amount of charge that is retained can rise to between 30-95% with the implementation of shut-off valves depending on system configuration, operating conditions etc.

A test method is therefore needed to accurately determine the amount of refrigerant that would leak, based on variations in system conditions. Therefore, to determine the minimum room size the system can be installed, only the amount of refrigerant charge that can be leaked from the system should be considered.

### 4.4.4 Housing design

Allowable charge limits in current safety standards are also based on the assumption that a leak does not mix easily in the surrounding air, therefore requiring a limitation on charge size to prevent flammable concentrations reached in a limited period. Research has demonstrated that the design of unit housings has a significant influence on the dilution of a refrigerant leak, up to a factor of 5 as compared to the assumption of "pure", undiluted refrigerant exiting the housing as in current safety standards.

As the relationship between housing design and subsequent refrigerant leak dilution is complex so type-testing can determine the maximum allowable refrigerant charge that can be used before flammability concentrations are reached. Therefore, a leak at an assumed rate can be simulated in any given housing design and refrigerant concentrations at the floor of the system can be measured. The allowable refrigerant charge can then be limited to an amount in which a flammable concentration does not occur, or occur within a given timeframe. This test method could be combined with the risk mitigation measures discussed earlier, such as improved system tightness and system integral airflow.

### 4.4.5 Sources of ignition

When determining whether electrical, or other items on refrigeration or air conditioning equipment, are potential sources of ignition, it is necessary to identify if they could be in a location that could ignite a leak of refrigerant. This is normally determined by area classification or 'zoning', and the most practical approach is to perform a leak simulation test.

In certain safety standards there is an absence of any such leak simulation test whilst in other standards, such tests are included but they differ widely across those standards For instance, in one standard it is specified to release the refrigerant at an extremely high mass flow rate, whilst in another standard that covers equivalent equipment but for a substantially larger charge size and possibly poor build quality the specified leak rate may be a fraction of it. As a result, it is not evident to manufacturers that build systems using flammable refrigerant how to consistently and reliably assess the risk of potential sources of ignition. This imposes a high level of uncertainty on manufacturers, not knowing whether their equipment achieves the desired level of safety. Alternatively, manufacturers simply select all electrical equipment to be x-rated – despite being unnecessary in most cases – which results in a very high cost burden and renders equipment uncompetitive.

EN 60335-2-40 includes a leak simulation test (Annex FF – Leak simulation tests). However, the test is not practicable for the majority of systems, and is contrary to the requirements of the ATEX harmonised standard, EN 60079-10-1, for hazardous area classification. This therefore imposes an additional complication to manufacturers since, in some cases, they will be unable to satisfy the test (as it is not possible to perform it). Further, they would then need to essentially repeat an alternative exercise to meet the ATEX requirements of, for example, EN 60079-10-1. This again incurs additional cost and creates uncertainty for the manufacturer who may be unsure as to how to apply the ATEX requirements.

For EN 60335-2-40, there are two main problems. The first relates to the specification of the mass flow rate being the entire charge released in four minutes through a capillary tube. Apart from this being inconsistent with the ATEX approach, it is also not practical for larger charges, for example, on a system containing several kilograms of refrigerant, it is not possible to vaporise such a quantity of refrigerant and then to pass it through a capillary tube . The second issue is where the test specifies the pass criterion as not exceeding 25% of LFL, which is substantially lower than the criteria for zone 2 area classification under the ATEX harmonised standards.

Currently, none of the international safety standards address the handling of potential sources of ignition in a way that is consistent with the established standards for protection against ignition of flammable gases. This specifically refers to the IEC / EN 60079-series of standards. ISO 5149 effectively neglects the issue and IEC 6035-2-40 and -89 partially address the issue but in a manner that is inconsistent with established methodologies. In this respect, revisions are necessary to all three international standards.

Similarly, it is recommended that the general standard for area classification EN 60079-10-+1 also be modified to reflect the practices and equipment peculiarities of the RACHP sector.

### 4.4.6 Industry feedback on mitigation measures

According to opinions from industry people, a small manufacturer might face difficulties financing equipment and time to do all the testing required. In addition, it was mentioned that measures can increase cost of design and for small leaks it can possibly be ineffective, whereas for larger charge sizes it will likely need to be utilized as part of a system safety approach.

It is widely agreed that improved system tightness to reduce probability of leaks should be a standard practice for any manufacturer, and is believed to reduce the risk extensively. On the other hand, a respondent indicated that improved charge leak test method to accurately determine the amount of refrigerant leak and inclusion of the housing design factor through individual testing that can determine the maximum allowable refrigerant charge, can already be done but they are difficult to standardise very well as the product ranges are too diverse.

One respondent indicated an additional mitigation measure; monitoring different parameters of the cooling system in order to detect a possible leakage. According to another respondent, the controlled volume inside the appliance where a leak may release refrigerant must be always free of potential ignition sources. Extra attention needs to be placed in this measure, even if it is already a mandatory requirement. Additional mitigation measures must focus on reducing the refrigerant amount that may be released to an uncontrolled potentially occupied room.

Among measures that are currently being used are:

- Placement of units outdoors
- Emergency ventilation for large systems placed indoors

- Gas detectors and measurement of air levels
- Increased safety of electrical circuits in stores

Overall, industry representatives unanimously believe that good education, frequent field training, and proper certification of technicians and engineers are significant mitigation measures that often gets overlooked and has the potential together with technical safety adaptations to reduce risks for flammable refrigerants.

# CONCLUSIONS

**EU F-Gas Regulation & hydrocarbon refrigerants**

The uptake of low-GWP alternatives such as hydrocarbons in Europe is strongly accelerated through legislation. At the EU level, the Regulation (EU) 517/2014 on fluorinated greenhouse gases (F-Gas Regulation) is a powerful driver for manufacturers and end-users to consider hydrocarbons for a variety of applications.

According to the data collected from leading manufacturers of hydrocarbon-based units, there are approximately 2.5 million plug-in refrigerated showcases / cabinets used in supermarkets. Similarly, the estimated number of hydrocarbon-base heat pumps today in Europe is between 200,000 - 220,000 units, while the number of portable ACs using hydrocarbons is above 200,000. R290 split AC units are not being currently sold in the European market.

The impact of the F-Gas Regulation on the uptake of hydrocarbons is reflected in the findings of the market research in this report, which indicates that most of the companies considering to start manufacturing hydrocarbon-based products plan to do that within the next 2-3 years. This timeframe is in line with the ban on HFCs (GWP > 150) in hermetically sealed commercial refrigeration set to take effect in January 2022. In addition, the growing HFC prices are expected to motivate manufacturers to consider hydrocarbons in heat pumps and AC.

In most cases, manufacturers currently produce hydrocarbon-based equipment in relatively small quantities compared to their HFC-based production. This is nevertheless expected to change not only as a result of the F-Gas Regulation but also the anticipated change in hydrocarbon standards. Especially in commercial refrigeration, where there are a large number of companies manufacturing small quantities of hydrocarbon-based equipment, the production can be scaled up rapidly.

**Initial & life cycle cost of hydrocarbon-based equipment**

Indications about the initial cost, energy efficiency and life cycle cost show a similar story for commercial refrigeration, heat pumps and air conditioning applications. Respondents indicated that hydrocarbon systems are slightly more expensive than their HFC counterparts. The higher initial cost is, however, offset by the energy efficiency gains of hydrocarbon refrigerant-based systems. Energy efficiency has an impact on the operational costs, which as a consequence bring the life cycle costs down. According to a substantial number of respondents, life cycle costs of hydrocarbon refrigerant-based systems are either on par or lower than current HFC- based technology.

**Charge limits & mitigation measures**

The current charge limits are prohibitive and obstructive for hydrocarbons. Overall, when aggregating the responses for all types of systems, it is evident that standards allowing higher refrigerant charges have the potential to remove barriers and restrictions and allow stakeholders to transition faster and without uncertainty to hydrocarbon refrigerants.

The key elements to make higher hydrocarbon charges a success in the market are:

- A **uniform change in the standards and formally approved at the EU level** as well as **integration into building codes**. It is important for manufacturing companies to be able to industrialise the process of producing new products with higher hydrocarbon charges.
- **Awareness raising** and **information sharing** about the safety of systems with

hydrocarbons, that are efficiently designed with negligible flammability risks.

- **Training and certification** of technicians to ensure they are able to safely install and handle equipment containing higher hydrocarbon charges. Introducing hydrocarbons manipulation and technology in professional schools for technicians, as well as introduction of mandatory certification are options to achieve these goals.

To support increasing the allowable refrigerant charge a series of mitigation measures can be implemented to offset potential risk of greater charge sizes and therefore support the utilisation of hydrocarbons in a far wider amount of systems applying European and international safety standards.

According to survey respondents, all safety issues and any potential malfunctions can be solved by a good combination of mitigation measures including intuitive control systems, a thorough risk assessment, good quality components, and skilled certified technicians to handle and maintain the systems.

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