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Briefing Paper: HFCs and HFC alternatives in split air conditioning systems

1 Introduction

The F-Gas Regulation (EU) No 517/2014 on fluorinated greenhouse gases (the F-gas Regulation) requests the Commission to assess, by mid-2020, if "cost-effective, technically feasible, energy-efficient and reliable alternatives exist, which make the replacement of fluorinated greenhouse gases (F-gases) possible in new small single split air conditioning systems" (Article 21.4). This briefing paper summarizes the consultations carried out in order to respond to this request. The presented findings are based on desk research and information obtained at trade conferences as well as through the consultation of targeted stakeholders.

2 Scope

This paper addresses the feasibility of using alternatives in new1 split air conditioning (A/C) equipment. To this purpose, it is useful to distinguish between different types of A/Cs and their sizes2:

- Single-split systems[3] consisting of (only) one indoor unit and one outdoor unit connected by a refrigerant-carrying pipe that require installation
  - Small single-splits: below 3 kg charge size[4] for a one-room solution;
  - Larger single-splits: above 3 kg charge size, for larger rooms.
- Multi-split systems consisting of one outdoor unit connected by refrigerant-carrying pipes to two or more indoor units of choice; suitable to create different room climate zones and/or for multiple rooms or large rooms.

3 Relevance of Alternatives

The principal focus of the Regulation's request is on **alternatives to F-gases**. However, **F-gases that have a lower global warming potential (GWP) than existing conventional refrigerants will also be considered** as alternatives in the current assessment, to the extent other alternatives with a lower GWP do not yet exist. In that case a transitional shift to F-gases with a lower GWP may at this stage result in an important reduction in the climate impact from new air-conditioning systems. Furthermore, for a refrigerant to be considered as an "alternative", it must be sufficiently safe and energy-efficient.

As for the latter, the principle used in this assessment is that a "real" alternative needs to ensure that the system using the alternative refrigerant can be at least as energy efficient as the conventional, F-gas based

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[1] Retrofit options are not in the scope of the study. Retrofit from A1 refrigerant to A2L or A3 refrigerant is not possible, regardless the equipment, for safety and warranty reasons. Associations have warned against doing so: https://www.racplus.com/news/dont-try-to-retrofit-r32-in-an-r410a-system-warns-feta-05-03-2018/ Moreover, the retrofit of split systems is rare given the price of the equipment.
[2] Another similar system are "ducted units", consisting of a central unit, usually located on the roof, connected by *air* ducts to air outlets and sensors in each room. They are often used for heating/cooling an entire house and common in the US, but rarely found in Europe. They are therefore not discussed further in this paper.
[3] According to definition 39 in article 2 of the F-gas Regulation
[4] In analogy to the prohibition Nr. 15 in Annex III of the F-gas Regulation

refrigerants on the market[5]. Equipment with alternatives must also comply with the efficiency standards of the Eco-design Directive, safeguarding that the positive climate impact of indirect emissions is also guaranteed.[6]

Safety aspects are important for putting into service, installation, maintenance and the full duration of regular use of products and equipment using F-gases. In addition, safety requirements exist for employers to ensure occupational health is guaranteed as well as requirements for production, logistics and end of life treatment of such equipment. Different refrigerants have different properties that must be taken into account when designing the equipment to make it safe. The safety group classification according to standard EN 378-1 consists of two characters: A capital letter corresponds to toxicity (2 groups: A and B) and a digit refers to flammability (1, 2, 2L, 3). The table below shows examples for the classification of different refrigerants into safety groups:

	Toxicity	
Flammability	**A:** lower toxicity	**B:** higher toxicity
1: non flammable	**R744 (CO_2)**, R410A, R466A	
2L: lower flammability	R32, R452B, R454C	**R717 (NH_3)**
2: flammable		
3: higher flammability	**R290 (propane), R1270 (propylene)**	

N.b: Only the refrigerants in bold are alternatives that are not F-gases

There are some use limitations related to these classifications, for instance in product standards and in local building codes that may pose barriers to using some of these refrigerants[7]. These limitations depend i.a. on the location of use (e.g. public access or not, room size), how the equipment is mounted (e.g. roof, ceiling, floor, wall) and the existence of risk minimization measures (e.g. fan). A 2016 EC report found "that standards (at international, European and national level) regarding the use of flammable refrigerants appear to be an important barrier to the uptake of climate-friendly alternatives to HFCs (EC, 2016). The most relevant standards for refrigeration, A/C and heat pumps are EN 378, as well as the product standards IEC EN 60335-2-40 (for air-conditioning systems) and IEC EN 60335-2-89 (for integral and remote commercial refrigeration appliances) which take precedence over EN 378. Before placing on the market of a new product, such standards are commonly applied by producers but are not mandatory to reach conformity with EU legislation as other methods for risk assessments can be equally used to prove safety of the product. Nevertheless, the need for further updating standards in Europe in line with technological development in order to allow for the safe use of flammable refrigerants still is perceived as a barrier by manufacturers and installers and inhibits further market uptake of flammable alternatives in refrigeration and A/C.[8] Until these barriers are removed, where justified and based on an empirical appreciation of the actual risks[9] to maintain acceptable safety levels, there will remain some obstacles for the introduction of climate-friendly solutions. Work is being undertaking on the product standard IEC 60335-2-40, that is

[5] As regards energy efficiency, the properties of the refrigerant are only one side of the coin; the other is system optimisation achieved by fine-tuning the relevant components to a certain refrigerant. Thus, further energy efficiency improvements can be expected through time & experience of manufacture and use of a new refrigerant.

[6] The Eco-design Directive sets efficiency standards for air-conditioners with a capacity of up to 12 kW.

[7] See EC report on barriers posed by codes, standards and legislation: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52016DC0749

[8] Some of these issues are being addressed by the EU funded research project LIFE FRONT. www.lifefront.eu/

[9] Significant research on the risks related to the use of flammable refrigerants in air conditioners has already been undertaken worldwide (e.g. Tang et al., 2018; Colbourne & Suen, 2015).

relevant for split A/C systems, to establish a maximum charge size of 1 kg for A3 refrigerants. Different precautionary measures will be required depending on charge and room size. In addition, a further need for trainings on flammable refrigerant use for installers and service companies has also been repeatedly emphasized by industry.[10]

In summary, an alternative refrigerant is only considered relevant in the context of this report if it has a very low global warming potential or if in the absence of such a low GWP alternative has a much lower GWP than the most prevailing technologies, it is sufficiently energy efficient (at least the same level of efficiency as conventional refrigerants) and can be used safely[11].

4 Technical feasibility

As regards the feasibility of using refrigerants, charge size is an important parameter. The most commonly used refrigerant in split A/Cs so far has been the HFC blend R410A. The average charge (kg) with this refrigerant depends on the typical average cooling capacity (kW) and would range between 0.25 kg/kW for single and multi-split systems with a cooling capacity < 7 kW and 0,34 kg/kW for multi-split systems with a cooling capacity < 17.5 kW (Uniclima, 2019). We can consider therefore that single-split equipment containing charges of HFC refrigerant < 3 kg as specified by the existing prohibition Nr. 15 (Annex III) thus relates to cooling capacities of <12 kW.[12]

The following table gives an overview over feasible refrigerants in split systems. These are discussed further in the sections 5 and 6 on market trends and ongoing R&D activities.

[10] EC Report COM/2016/0748 on availability of training: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52016DC0748

[11] While it is not possible in the scope of this paper to exhaustively address all limitations posed by codes and standards

[12] This is similar to the scope of Regulation 206/2012 that sets ecodesign requirements: The scope for air conditioners is limited to "air conditioners with a rated capacity of ≤ 12 kW for cooling, or heating if the product has no cooling function".

Refrigerant	**GWP (4AR)**	**Relevant use restrictions**	**Feasibility for different types of split A/C**	**Market readiness**	**Current production capacity of split A/C**	**Energy efficiency**
R410A	*2088*	*A1* *No restrictions*	*All*	*Yes*	*High*	*Baseline*
R32	675	A2L Charge size limited by product standards/building codes.	All	Yes	High	Better than R410A[13],[14]
R290	3	A3 Charge size limited by product standards/building codes. Some prohibitions (for instance in high-rise buildings in France).	Single split currently up to 7 kW. Potential also for larger single & multi-splits if increase of charge limits in standards.	Yes	ca. 7millions of R290 split units per year in China (UNEP, 2019)	Similar to R32; especially under high ambient temperatures[15],[16]
R1270	2	A3 Manufacturers have concerns about stability of the refrigerant. Charge size limited by product standards/ building codes.	Yes, but mainly used in chillers today.	No		Similar to R290[17]
R161	12	A3 Use may be prohibited locally. Toxicity testing incomplete.	Principally feasible	No Ongoing research	None	High[18]
R452B	698	A2L	All	No. Possibly conversion of R22 production lines in Egypt from 2020 (UNEP, 2019a)		Similar, slightly better at elevated temperature (>35°)[19]
R454B	466	A2L				Similar, slightly better at elevated temperature (>35°) [19]

[13] Based on thermodynamic properties, the COP (Coefficient of Performance) of R32 is 1,05 times higher than R410A. Source: AFCE study on alternatives.
[14] Mota-Babiloni et al., 2017
[15] Source: AFCE study on alternatives
[16] Li Tingxun (Midea/ Sun Yat-Sen University) 2019; R290 RAC, presentation given at consultation meeting for HPMP implementation in Brazilia, Brasil, November 2019.
[17] Makhnatcha, 2014 (heat pumps)
[18] Devotta et al., 2016
[19] Sethi & Yana Motta, 2016

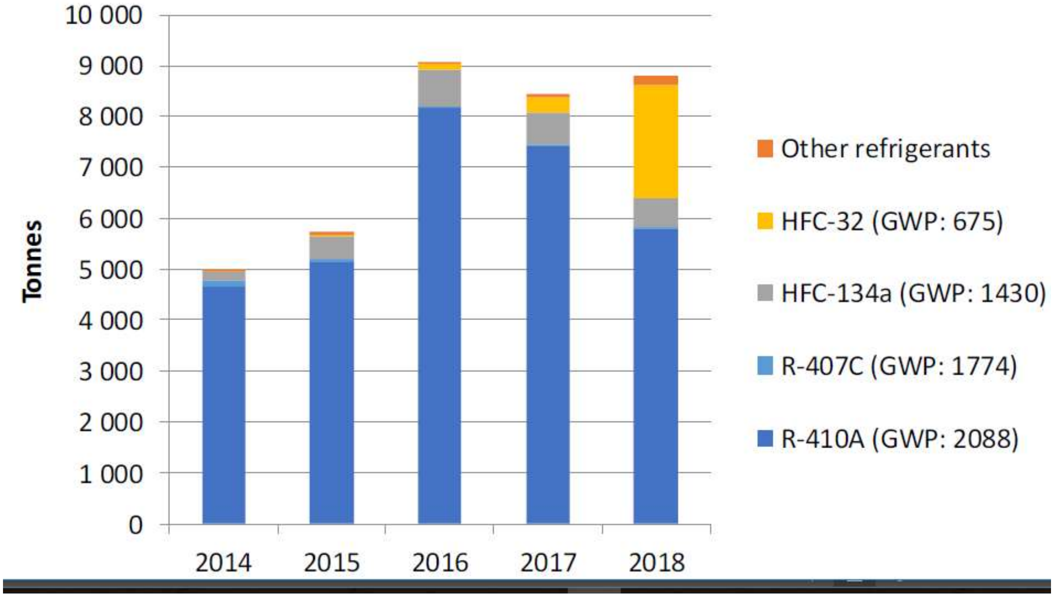
R466A	733	A1		No	No	Similar[20]
Other mixtures containing R1123 (trifluoroethylene), R1132a (1,1-difluoroethene) and CF3I (tri-fluoroiodomethane)	Ca. 300	No safety classification yet for the blends but R-1132a is A2, CF2I is A1 and R-1123 is A2L (expected)	unknown	No	No	Ongoing research

N.b: Only the refrigerants in bold are alternatives that are not F-gases

5 Market overview and trends

The annual company reporting on F-gases under Regulation 517/2014, Article 19, provides **import data** on F-gases in products and equipment. From Figure 1 below (EEA, 2019) it is obvious that the import of R32, which is mostly used in A/C, in appliances has increased significantly in 2018.

Figure 1. Refrigerants in imported stationary refrigeration and A/C equipment (metric tonnes).

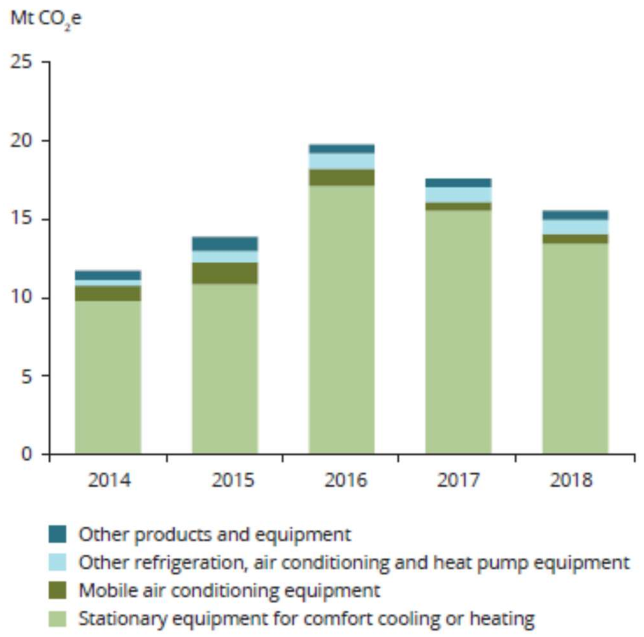


This has in turn resulted in a significant reduction of total CO2 equivalents of imported refrigerants in stationary A/C equipment (Figure 2, source: EEA, 2019) in the last two years.[21]

[20] Schultz, 2019

[21] The increases until 2017 are attributed to an incomplete coverage of reporting companies.

Figure 2. Total CO2 equivalents in different types of imported F-gas equipment



Sources: EEA (2018, 2019b).

In the following, the **market trends** for the most relevant refrigerants in split A/C are discussed:

- **R410A** represented the most common refrigerant for split A/C applications on the EU market for many years, but its share in single splits sales in 2018 and 2019 in the EU has been decreasing and replaced with R32. It is still the dominant refrigerant for multi-split systems and other larger A/C systems placed on the market in the EU today. One EU-based producer of A/C equipment started to use reclaimed refrigerants (R410A and R134a) in the manufacture of new equipment in 2019 to limit the impact on F-gas quota.

- **R32** was introduced to the market in Japan in the 2010s. It has been now been adopted by all major manufacturers of A/C equipment in their product portfolio for the EU market since 2013. The use of R32 in single-split systems also allows to reduce the refrigerant charge by about 20% to achieve the same cooling capacity. However, the current reduction of charge is only about 10% compared to R410A because of relevant ecodesign requirements[22].

  R32 is currently the dominant A2L refrigerant for single-split sales in the EU due to its product cost/performance aspect as efficiency was found to be comparable or better to R410A[23]. The share of R32 units out of single-split A/C sales varies however between EU Member States: In most countries a market share of more than 80% has been reached in 2019. In Italy and Spain building codes and installation requirements have been changed in the last two to three years to facilitate the use of flammable refrigerants. In this way, R32 split A/C units have gained higher market shares but are still somewhat lagging behind other EU countries. In France, national legislation about the use of flammable refrigerants in public access building (legislation CH35) has evolved in 2019, but still contains certain constraints depending on whether the refrigerant is A2L or A3. In the case of high-rise buildings, the use of A2L and A3 refrigerants is prohibited but some work on related legislation is still ongoing. About 60% of split systems put on the French market in 2019 were using

[22] Ecodesign demands a higher energy efficiency, which is obtained by increasing the refrigerant charge by 10% in the case of R32 units.
[23] Theoretically other refrigerants like R134a would have higher efficiency, but it has a higher volumetric capacity than R410A so the product cost due to a larger condenser required would be too high.

R32. A roadmap has been established by the national association and all the manufacturers are committed to using a refrigerant with GWP < 750 in split systems with a refrigerant charge < 3 kg before 2022.

According to BSRIA (Building Services Research and Information Association), R32 split units accounted for 37% of the total European A/C and heat pump market in 2019 and that share is expected to grow until 80% in 2023[24]. These figures are consistent with estimates provided by several stakeholders. The range of products containing R32 is not limited to single split A/C systems, but has been expanded to multi-split and even VRF systems[25] recently.

From a technical point of view, the market potential of R32 is 100% for single-split A/C units in 2020. Nevertheless, several technical experts as well as service technicians believe that R32 represents only an interim solution because they consider its GWP is too high to allow meeting the 2030 HFC phase-down reduction target.

- **R290** has been used in moveable A/Cs[26] by Asian and European equipment producers for a number of years. From 2020 onwards, R290 is expected to be the refrigerant of choice for this type of application due to the placing on the market prohibition set out by the EU F-gas Regulation (Annex III (point 14)). Major Asian equipment manufacturers perceived this policy measure as the main driver for the market uptake of hydrocarbon-based products.

Since 2012, R290 has also been used by some major Chinese and Indian manufacturers in commercially available split A/Cs (cooling capacity up to 7 kW). The use of R290 in single split systems allows for a reduction of the charges to about 40% compared to R410A (UNEP, 2014). Material costs for R290 units can thus be lower than for units running on R410A or R32. However, production costs are still somewhat higher than for HFC units (+6-10%) due to additional safety measures[27]. Energy efficiency levels of R290 split units are very similar compared to R32 units[28] and perform well under high ambient temperature conditions[29].

The conversion of production capacities for split A/C units in China from R22 to R290 of approximately 4 million units per year has been completed in 2014 (Zhou, 2014). The current production capacity for R290 split A/C units ranged at about 7 million units per year in 2019 (UNEP, 2019). Manufacturers have published a schedule for increased production numbers from 2018[30], aiming at the European market. For 2020, a production target of 330,000 R290 split units has been set[31]. The globally installed base is about 1 million units today, mainly in India and China.

Certain models of the range of split A/Cs offered by a Chinese manufacturer (2.6/3.5 kW cooling capacity) were granted the German ecolabel “Blue Angel” in 2018. For 2020, a large Chinese manufacturer is planning to start commercialization of a new single-split R290 split A/C system on the EU market.

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[24] https://www.coolingpost.com/world-news/r32-splits-accounted-for-37-of-the-market-in-2019/ (16.02.2020)

[25] VRF refers to Variable Reversible Flow which is used to describe large-scale ductless systems that provide heating and cooling. These systems are not included in the split system category of this paper.

[26] Not considered part of the split A/C category

[27] Information provided by a Chinese manufacturer during personal communication, October 2019.

[28] Li Tingxun (Midea/ Sun Yat-Sen University) 2019; R290 RAC, presentation given at consultation meeting for HPMP implementation in Brazilia, Brasil, November 2019.

[29] Abdelaziz and al. 2016

[30] https://hydrocarbons21.com/articles/9129/chinese_companies_report_sales_of_nearly_160_000_propane_room_acs (28.02.2020)

[31] Information provided by the Chinese Ministry of Ecology and Environment (MEE)/Foreign Environment Cooperation Center (FECO) during personal communication, October 2019.

The EU funded research project LIFE ZEROGWP (2018-2021) intends to demonstrate the technical feasibility, full safety and commercial viability of an innovative residential A/C system based on Double Duct (DD) technology[32].

6 Alternatives in the pipeline

There are also a number of R&D activities in and outside the EU that aim at replacing R410A in A/C applications including split systems, as follows.

- **R161** (GWP 12; safety class A3) has been used in research on split AC to replace R22 (Devotta et al. 2016) and a demonstration project in China where a household air conditioner was developed[33] but is not commercially available. The safety classification of R161 is incomplete due to the lack of toxicity testing.
- **R452B** ("Opteon XL55"; GWP 698; safety class A2L), has been approved by one component manufacturer for use in their scroll compressors[34]. It is contained in industrial equipment such as reversible heat pumps and chillers supplied by several distributors in the EU, but not in split A/C at this stage.
- **R454B** ("Opteon XL41"; GWP 467; safety class A2L), has so far been approved by one component manufacturer for use in their scroll compressors. In Egypt, some split A/C manufacturers are considering to convert their production to this refrigerant within the HCFC phase-out under the Montreal Protocol and see it as an alternative to R32 (UNEP, 2019a).
- **R454C** (GWP 148; safety class A2L) has been applied in Japan in air to air heat pump for commercial use and in an air-to water heat pump by a German manufacturer[35]. It is also considered as an option for room A/C applications in the future.
- Further options that include R466A and mixtures with HCFOs or CF3I are at an early stage of refrigerant testing. Their suitability for split systems is not clear.
- Further research by Industry within and beyond EU is directed towards lower GWP alternatives, aiming at a GWP below 10 (e.g. NEDO project, 2018-2023).

7 Conclusions

On the basis of the above, it seems technically possible to avoid F-gases today in new single split A/C with a cooling capacity below 7 kW by using the refrigerant R-290, unless where national legislation or codes prohibit its use, at good energy efficiency and at a very modest price increase that would likely disappear due to economies of scale if used at large scale.

For single split systems > 7 kW it still appears necessary at this stage to use F-gases. In this case, the use of R32 is preferable to R410A, which has been the conventional refrigerant choice hitherto, because the GWP for R32 is 3 times lower and it is at least as energy- and cost-efficient as R410A. Thus, refrigerants with a GWP > 750 in new equipment are not anymore needed in small single split systems[36], unless in application areas where it is still prohibited to use a flammable refrigerant by building codes and other legislative requirements.

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[32] In a double duct system, warm air and cool air travel through separate ducts and are mixed to reach a desired temperature.
[33] https://www.ashrae.org/about/news/2019/ashrae-un-environment-programme-announce-lower-gwp-award-selections
[34] https://www.coolingpost.com/products/danfoss-approves-lower-gwp-options-for-dsh-scrolls/ (27.02.2020); scroll compressors are widely used in air conditioning and heat pump equipment and use two interleaving scrolls to compress refrigerants.
[35] www.coolingpost.com/products/stiebel-eltron-launches-r454c-heat-pump (19.02.2020)
[36] Defined by the F-gas Regulation to have a charge size of <3kg

An assessment of the current EU market shows that the majority of single split systems sold in the EU no longer contain R410A. This shift has been driven by the HFC phase-down measure including the requirement for pre-charged equipment to be covered by the quota system. A large part of the market is hence already in compliance with the requirement to use refrigerants in small single splits with a GWP of less than 750 from 2025[37].

It is expected that knowledge, practices and know-how related to flammable refrigerants in the production, installation, use and end of life management of A/C equipment will be further refined in the next years. Similarly, it is expected that further progress will be made on the revision of standards and codes to better account for the technological development. Furthermore, taking into account that a number of new blends with low GWP are in the pipeline, it is likely that **further alternatives will become market ready in the foreseeable future**. A further significant reduction of GWP of the alternatives to e.g. below 150 may be possible in all small single split systems in the medium term.

The market assessment also shows that several manufacturers/importers are already selling larger single split A/C systems (with charge > 3 kg), multi-split systems and other types of A/C systems (e.g. VRF systems and chillers) that are not using the traditional refrigerant R410A anymore. Again, the dominant refrigerant is R32, but also some applications relying on R290 as well as HFO-based refrigerants are available. Given that many of these equipment types use higher charge sizes, which is making the use of flammable refrigerants more challenging, a complete phase-in of more climate-friendly refrigerants will take some time in these types of equipment, but good progress is expected in the medium term.

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