HPT Annex 54

Heat Pump Systems with Low GWP Refrigerants

Task 1: State of the Art

Country Report

AUSTRIA

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Executive Summary

National and international regulations aim to reduce the greenhouse gas emissions caused by the release of refrigerants to the atmosphere by defining restrictions for refrigerants with high GWP-values in certain applications and by limiting the total CO_2-equivalent of refrigerants on the market through a phase-down concept. However, currently most used refrigerants have GWPs in the magnitude of 1000 or even more. While in other sectors like refrigerators or freezers, natural refrigerants as e.g. R290 and R600a can easily be used, for heat pumps the situation is different, also due to higher capacities and higher refrigerant charges.

This report defines, based on an analysis of existing legislative material, what “Low GWP” means in terms of maximum GWP and gives a short overview of important standards. It characterizes the most important physical properties that are important for an efficient use and for safety reasons and compares the relevant properties of currently used refrigerants with those of possible alternatives. The report moreover identifies Low GWP refrigerants and gives an overview of the Austrian heat pump market. Finally, it contains examples of Low GWP refrigerants in applications other than domestic heat pumps.

It is shown that most regulations are based on the assumption that a GWP of 150 or below is unproblematic so that they stay unregulated at least. Therefore, the report concludes that the GWP threshold for Low GWP refrigerants shall be 150. However, GWP is not the only physical property to focus on when a refrigerant is selected. A refrigerant must meet a lot of requirements to be suitable for a certain purpose (system temperatures, size, location, etc.). Among them, there are saturation pressure and volumetric cooling capacity, important for the necessary size of the cooling cycle components, the realizable power and the efficiency of a system. The safety class, indicating the flammability and toxicity, are of great importance as well. It is shown that a low GWP goes in line with a higher flammability, which is of course problematic to some extent. R290 turns out to be the only refrigerant that is currently used as Low GWP refrigerant in heat pumps, and there is no sign that others like CO_2 could gain importance in the near future. However, R290 is highly flammable and therefore not suitable for all applications. It is concluded that in some cases Low GWP refrigerants, based on the definition of GWP_{max} of 150, do not exist. A higher GWP threshold would therefore make sense in such cases.

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1. Introduction

In this report the focus shall be on heat pumps with Low GWP (global warming potential) refrigerants for domestic purposes and similar use as e.g. in offices. High temperature heat pumps for industrial purposes, freezing or large machines as for feeding into heat grids shall not be considered. Machines primarily used for cooling e.g. in offices which can also be used for heating, shall not be included either.

1.1 Definition of “Low GWP”

There is of course no scientific threshold for a low GWP value under which a refrigerant can be called harmless in terms of global warming potential, therefore this value has to be defined artificially. A proper basis for this report is built by various present or also superseded EU regulations, which are presented in the following.

- COMMISSION DECISION of 28 May 2014 establishing the criteria for the award of the EU Ecolabel for water-based heaters 2014/314/EU [01], Criterion 3 on refrigerants: The global warming potential over a 100 year period (GWP100) of the refrigerant shall not exceed a value of 2000.
- DIRECTIVE 2006/40/EC [02] of the European Parliament and of the Council of 17 May 2006 relating to emissions from air-conditioning systems in motor vehicles aims at “prohibiting from a certain date air conditioning systems designed to contain fluorinated greenhouse gases with a global warming potential higher than 150“.
- REGULATION (EU) No 517/2014 [03] of the European Parliament and of the Council of 16 April 2014 on fluorinated greenhouse gases: various obligations and restrictions start from a GWP above 150. E.g. domestic refrigerators and freezers that contain hydrofluorocarbons (HFCs) with GWP of 150 or more have been banned from the market since 2015.
- REGULATION (EC) No 842/2006 of the European Parliament and of the Council of 17 May 2006 [04] on certain fluorinated greenhouse gases: This regulation was repealed by 517/2014 [03]; however it mentioned the threshold of < 150 as well.
- Moreover, the EHPA Quality Label [05] by the European Heat Pump Association states minimum SCOPs for heat pumps in order to be called a high quality heat pump. For the seasonal coefficient of performance (SCOP) values set there is a facilitation for heat pumps with a refrigerant with a GWP of less than 150: “For heat pumps that use a refrigerant with a GWP less than 150, the minimum requirements of the coefficient of performance (COP) shall be reduced by 15 %.”

The majority of regulations seems to set the border at a GWP of 150, which shall therefore be adopted in this report. (Whether a refrigerant with a GWP of exactly 150 is included or not, is differently defined in the regulations, but as there is no refrigerant known with GWP = 150, this is not relevant.)

In the 5th IPCC assessment report [06] (International Panel on Climate Change), the most recent GWP values are listed which shall be taken as basis for this report.

1.2 Refrigerant properties

Safety classes (consisting of toxicity and flammability), saturation pressure (dew point if zeotropic mixtures are considered) and volumetric cooling capacity are important parameters for the characterization of refrigerants. They are described in the following.

1.2.1 Safety classes – toxicity and flammability

Besides GWP, two very important characteristics of refrigerants are toxicity and flammability. Regarding those two parameters, refrigerants are classified into safety classes (Table 1-1, see also EN 378 [07] and IEC 60035-2-40 [08]).

The widely used safety classification scheme for refrigerants, provided in ISO 817:2014 [09] resp. ASHRAE Standard 34-2019 [10] is regarding toxicity and flammability (see Table 1-1).

Toxicity:
Toxicity is low (class A), when 400 ppm of the respective refrigerant in air have no negative impact on most employees, which are daily exposed to this concentration during an 8h working day resp. a 40h working week. Toxicity is elevated (class B) when a concentration of below 400 ppm can have a negative impact [11]. Ammonia is a rare example of toxicity class B refrigerants.

Flammability:
Regarding flammability, refrigerants are divided into four classes (1, 2, 2L und 3). Class 3 means flammable refrigerants with a combustion enthalpy > 19 MJ/kg or a lower explosion limit of < 100 g/m³. In class 2 there are refrigerants with low flammability, with a combustion enthalpy < 19 MJ/kg and the lower explosion limit > 100 g/m³. In class 2L the max. flame spread is < 10 cm/s. Non-flammable refrigerants are in class 1 [11].

Common hydrofluorocarbon (HFC) and hydrochlorofluorocarbon (HCFC) refrigerants were developed to achieve a high safety level and hence, have a low toxicity and no flammability (safety refrigerants). Therefore, they are classified as A1 refrigerants. Because of their high GWP, the regulatory framework [03] demands their replacement by alternative refrigerants with a lower GWP. Many potential alternative refrigerants have some flammability but also lower toxicity and hence, are classified as A2L (new unsaturated fluoro-chemicals) resp. A3 (hydrocarbons).

Table 1-1: Safety classification of refrigerants according to ISO 817:2014 [09], [10], [13]

Flammability ↑ / Toxicity →	Lower Toxicity	Higher Toxicity
No flame Propagation	**A1:** CFC, HCFC, most HFCs	**B1:** Seldom used
Lower Flammability	**A2L:** Most HFOs, R32	**B2L:** Ammonia
Flammable	**A2:** R152	**B2:** Seldom used
Higher Flammability	**A3:** Hydrocarbons	**B3:** no refrigerants

1.2.2 Saturation pressure

The operating temperatures of domestic heat pumps are determined by the heat source temperature and heat sink temperature. The heat source can be ambient air for air source heat pumps, which strongly depends on the climate conditions, or soil or ground water for ground source heat pumps. The heat sink temperature depends on the used heat distribution system. With given sink and source temperatures, the configuration of the heat pump is crucial for the occurring evaporation and condensation temperatures. The relevant pressure levels of the heat pump (evaporation and condensation pressure) depend on the saturation pressure of the used refrigerant and provide information regarding the applicability of components. If the saturation pressures of two refrigerants are similar, it is likely that the components can be utilized with both refrigerants from a strength point of view.

1.2.3 Volumetric cooling capacity

The volumetric cooling capacity determines the required volumetric refrigerant flow for a given cooling capacity, which in turn yields the respective heating capacity. This property determines the size of the needed system components and is evaluated according to Eq. 1 with the vapor density (ρ'') and the enthalpy of vaporization ($h'' - h'$).

$$q_0 = \rho'' \cdot (h'' - h')|_{p=const.} \qquad \text{Eq. 1}$$

2. Standards Regarding Safety and Refrigerant Charge Limits

The 1985 developed "New Approach", as stated in the EU Blue Guide (2016) [14], connects legislation and standards regarding product rules in the EU. It follows the principle that legislative harmonisation should be reduced to essential requirements and the technical specifications for products meeting these essential requirements are defined in harmonised standards. Since the application of harmonised standards implies conformity with the corresponding essential requirement of the applicable legislation, a manufacturer can either conform to a harmonised standard or comply with the legislation directly. Through the application of harmonised standards, manufacturers can benefit from a simplified conformity assessment procedure. The European Commission offers a (not legally binding) comprehension of harmonised standards on their web pages [15].

Standards can also be divided into "vertical" standards, theoretically aiming at specific product types and "horizontal" or "group" standards covering an entire sector [16]. EN 378 [07] is an example for a horizontal standard, while the IEC 60335-2 series (e.g. [08]) can be seen as vertical standards.

EN 378:2018 [07] covers stationary and mobile refrigerating systems including heat pumps. The Standard consists of the following four parts:

- Part 1: Basic requirements, definitions, classification and selection criteria
- Part 2: Design, construction, testing, marking and documentation
- Part 3: Installation site and personal protection
- Part 4: Operation, maintenance, repair and recovery

Part 1 includes refrigerant charge limits depending on the safety class of the refrigerant (flammability and toxicity are treated separately), access category and location of the system. In case of more restrictive national or regional regulations, the regulations with more restrictive limits apply. Appendix E lists safety relevant characteristics of refrigerants such as safety class, concentration limits regarding toxicity and flammability, vapour density at 25 °C, the ignition temperature as well as environmentally relevant characteristics such as GWP and ozone depletion potential (ODP).

An informative note of the "Bundesinnungsverband des Deutschen Kälteanlagenbauerhandwerks" [17] points out that EN 378 is legally binding due to the references made in part 2 which is harmonised.

Other safety relevant EU directives are:

- Pressure Equipment Directive (PED) 2014/68/EU [18]: Relationship between EN378 and the essential requirements of the PED are listed in EN378-2:2016 Annex ZA [19]
- Machinery Directive (MD) 2006/42/EG [20]: Correspondence between EN378 and the MD are listed in EN378-2:2016 Annex ZB [19]
- Low Voltage Directive (LVD) 2006/95/EC [21]
- ATEX directives 2014/35/EU [22] if flammable refrigerants are used

Additional requirements for flammable refrigerants are covered in EN378-2:2018 [19]. Appliances in the scope of and complying with EN 60335 also comply with the regulations concerning protection against fire and explosion hazards in EN 378. ÖNORM EN 60335-2-40:2014 “Household and similar electrical appliances – Safety – Part 2-40: Particular requirements for electrical heat pumps, air-conditioners and dehumidifiers (IEC 60335-2-40:2002 + A1:2005 + A2:2005, mod. + Cor.1:2006)” [08] is the national implementation of the corresponding IEC standard.

Other parts of the IEC 60335-2 series covering refrigeration equipment are:

- IEC 60335-2-24 “… Particular requirements for refrigerating appliances, ice-cream appliances and ice makers”
- IEC 60335-2-89 “... Particular requirements for commercial refrigerating appliances and ice makers with an incorporated or remote refrigerant unit or motor-compressor”

3. Present Situation of Refrigerant Use in Austria's Heat Pump Market

In Austria, conventional refrigerants based on hydrofluorocarbons (HFCs) are still widely used [23]. The most commonly used refrigerant is R410A, which is applied by all of the 36 heat pump manufacturers (incl. importers) in Austria, whose heat pumps are listed in the list of heat pumps eligible for public grants [23]. But the trend to new refrigerants substituting the conventional safety refrigerants (see below) is already perceivable: eight heat pump manufacturers resp. importers use R290 (Propane) in at least one of their heat pump models and four heat pump manufacturers resp. importers have experience with R32, which will be the widely used to substitute for R410a.

The following table shows the number of producers and models sold in Austria, for which the consumer can receive federal subsidies (status January 2020) [23]. The only refrigerant with a GWP below 150 is propane – R290. Market data in terms of sold products is sensitive data and therefore not reportable.

Table 3-1: Producers and models of heat pumps which are eligible for public grants in Austria distinguished by the used refrigerant (based on [23])

				of which:			
Refrigerant	**GWP**	**Producers**	**Models**	**A/W**	**B/W**	**DX/W**	**W/W**
R134a	1430	6	29	0	21	0	8
R290	3	8	37	34	2	0	1
R32	677	4	96	90	6	0	0
R407C	1774	14	284	105	108	12	59
R410A	2088	36	1442	831	396	14	201
R449A	1397	1	2	2	0	0	0
R452B	676	1	2	2	0	0	0
R454B	466	1	5	5	0	0	0
R513A	631	1	1	1	0	0	0
Sum		36	1898	1070	533	26	269

Also R404A (GWP = 3822) and R417A (GWP = 2346) is used in some models.

Figure 3.1 resp. Figure 3.2 show the relative number of air/water resp. geothermal heat pump models that are in the list of heat pumps eligible for public grants in Austria distinguished by the used refrigerant.

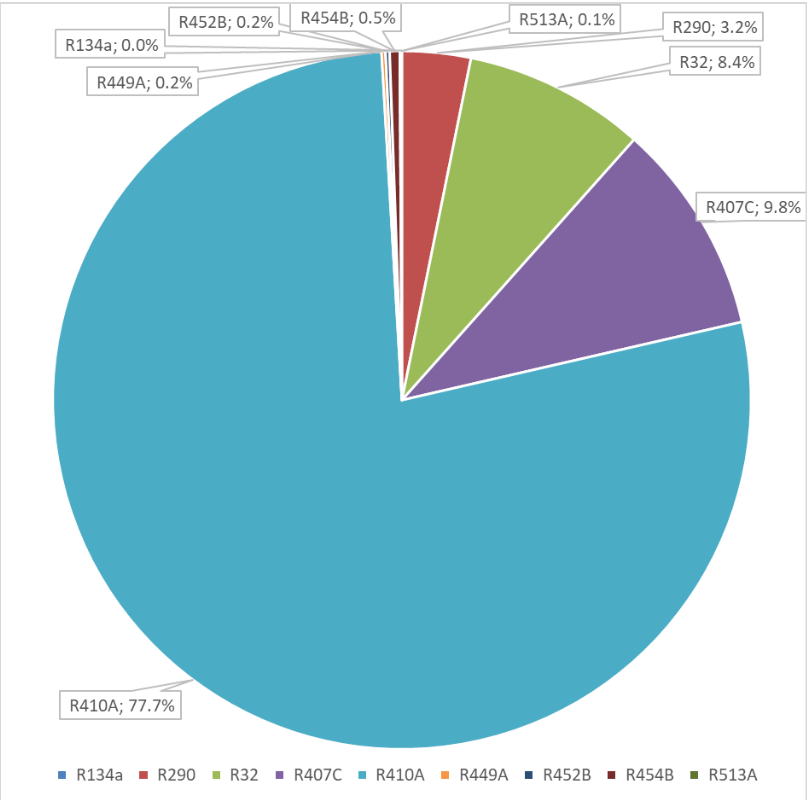

Figure 3.1: Relative number of air/water heat pump models, which are in the list of heat pumps eligible for public grants in Austria using the respective refrigerant [23]

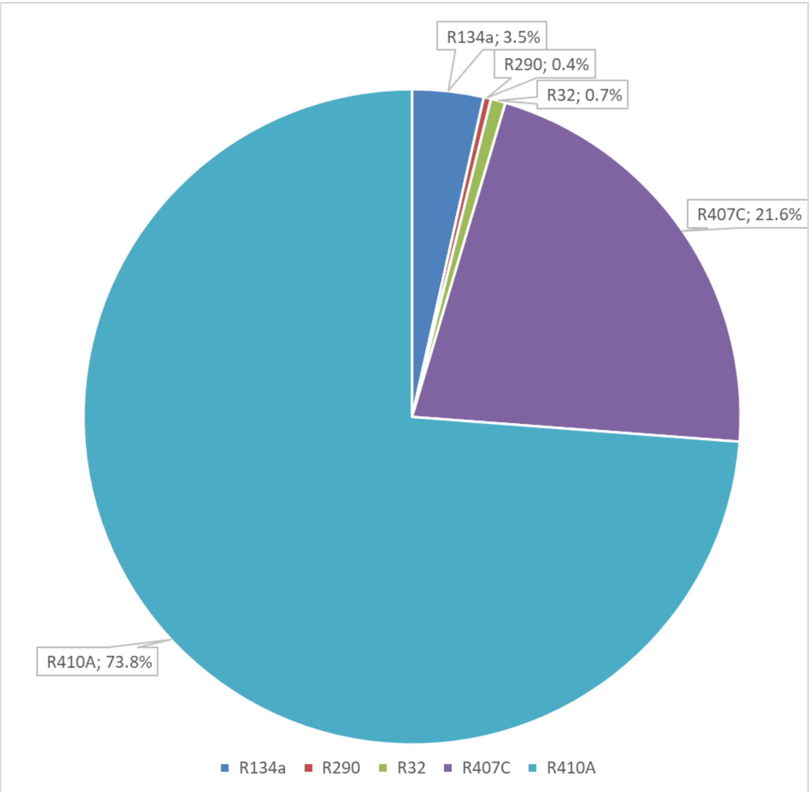

Figure 3.2: Relative number of geothermal heat pump models, which are in the list of heat pumps eligible for public grants in Austria using the respective refrigerant [23]

4. Low GWP refrigerants

4.1 Already available products and products under development

Many of the Low GWP refrigerants that are already available at the market, are blends of HFCs and hydrofluoroolefines (HFOs) [24]. Figure 4.1 shows the composition of these substitutes for conventional safety refrigerants. It can be seen that very few of the already available Low GWP refrigerants are single component refrigerants.

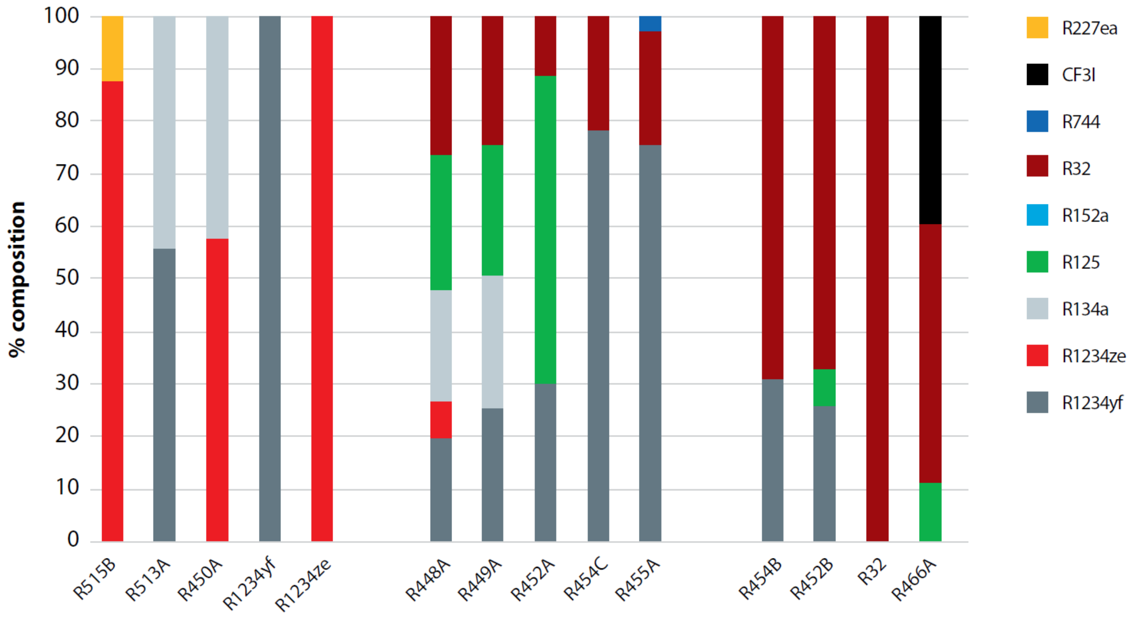

Figure 4.1: Composition of substitutes for conventional safety refrigerants [13]

Figure 4.2 shows the most common refrigerants with their substitutes and presents the achieved GWP levels of each new refrigerant indicating the quite huge leap in GWP from the old to the new chemicals.

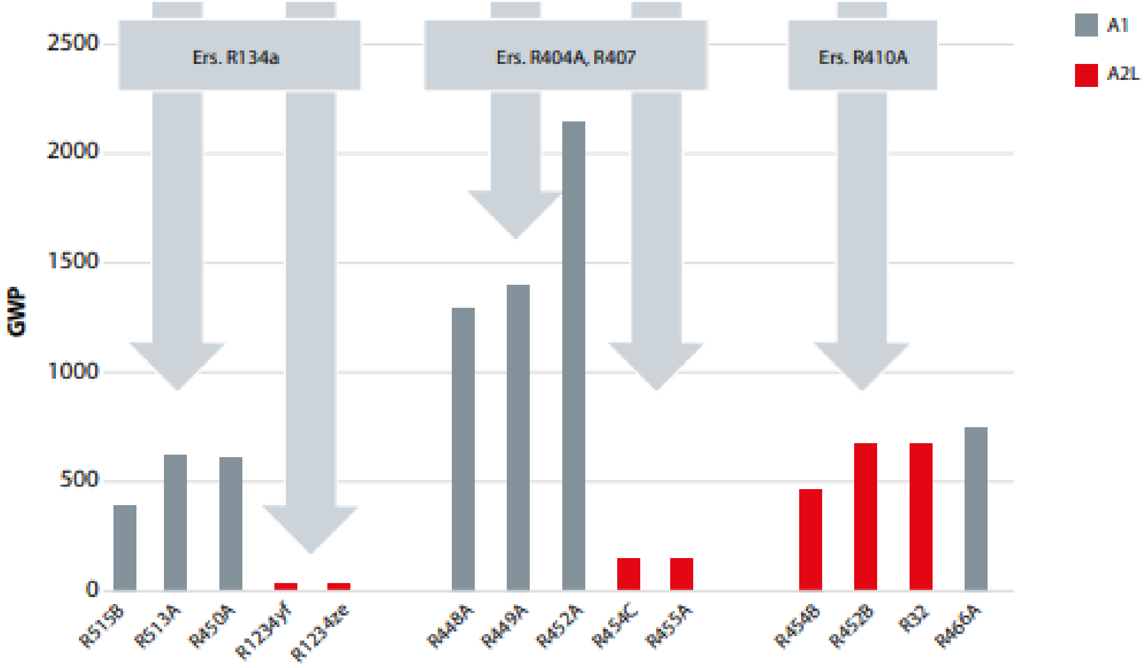

Figure 4.2: Conventional safety refrigerants and the GWP levels of their Low GWP substitutes [13]

4.2 Possible alternatives to currently used refrigerants

A screening of the currently used refrigerants was performed by means of a literature and market research revealed that R134a, R410A and R407C are commonly used refrigerants in heat pumps. Properties of these refrigerants and relevant alternatives as proposed by [25] are listed in Table 4-1.

Table 4-1: Overview of currently used refrigerants (bold) and possible alternatives. If not stated explicitly, data extracted from EN378-1:2016/prA1:2019 [26]. Other sources: a [27], b Refprop 10 [28], c [29], d Refprop 10 user defined mixture [28], e [30], f [31], g [25]

ASHRAE-number	Composition [$\%_{mass}$]	ODP	GWP_{100} AR4 (AR5)	Temperature glide @ 1 bar [K]	ASHRAE safety class	t_{krit} [°C]	p_{krit} [bar]	q_0 @ 0 °C [kJ/m³]
R134a	**-**	**0**	**1430 (1300)**	**-**	**A1**	**101** [a]	**40,6** [a]	**2868** [a]
R1234yf	-	0	4 (<1)	-	A2L	94,7 [a]	33,8 [a]	2888 [a]
R1234ze(E)	-	0	7 (<1)	-	A2L	109,4 [a]	36,3 [a]	2195 [a]
R444A	R32/152a/1234ze(E) 12/5/83	0	93 (89)	11,1 b	A2L	106,4 [b]	44,7 [b]	2762 [b]
R516A	R1234yf/134a/152a 77,5/8,5/14 [c]	0 [h]	142 (131) g	-	A2L [c]	96,7 [c]	36,2 [c]	2939 [d]
R515B	R1234ze(E)/227ea 91,1/8,9 [g]	0 [e]	293 (299) g	-	A1 [e]	108,9 [e]	36,0 [e]	2142 [d]
R450A	R134a/ 1234ze(E) 42/58	0	605 (547)	0,6 a	A1	104,5 [a]	38,2 [a]	2465 [a]
R513A	R134a/R1234yf 44/56	0	631 (573)	-	A1	94,9 [a]	36,5 [a]	3052 [a]
R456A	R32/134a/1234ze(E) 6/45/49	0	687 (629)	5,4 [b]	A1	102,7 [b]	41,8 [b]	2811 [b]
R407C	**R32/125/134a 23/25/52**	**0**	**1774 (1620)**	**7,0** [a]	**A1**	**86,2** [a]	**46,3** [a]	**4289** [a]
R454C	R32/R1234yf 21,5/78,5	0	148 (146)	7,8 [a]	A2L	85,7 [a]	43,2 [a]	4148 [a]
R455A	R744/32/1234yf 3/21,5/75,5	0	148 (146)	13,0 [a]	A2L	85,6 [a]	46,5 [a]	4419 [a]
R457A	R32/1234yf/152a 18/70/12	0	139 (139)	7,1 [b]	A2L	90,0 [b]	43,0 [b]	3802 [b]
R459B	R32/1234yf/1234ze(E) 21/69/10	0	145 (143)	8,2 [b]	A2L	87,5 [b]	43,6 [b]	3996 [b]
R465A	R32/290/1234yf 21/7,9/71,1 c	n.a.	145 (143) g	10,7 [d]	A2	81,6 [c]	43,4 [c]	4453 [d]
R448A	R32/125/1234yf/134a/1234ze(E) 26/26/20/21/7	0	1387 (1270)	6,3 a	A1	82,7 a	46,0 a	4738 a

ASHRAE-number	Composition [$\%_{mass}$]	ODP	GWP_{100} AR4 (AR5)	Temperature glide @ 1 bar [K]	ASHRAE safety class	t_{krit} [°C]	p_{krit} [bar]	q_0 @ 0 °C [kJ/m³]
R449A	R32/125/1234yf/134a 24,3/24,7/25,3/25,7	0	1397 (1280)	5,7 a	A1	82,1 a	45,0 a	4675 a
R460B	R32/125/134a/1234ze(E) 28/25/20/27	0	1352 (1240)	8,6 b	A1	88,1 b	48,9 b	4312 b
R449C	R32/125/1234yf/134a 20/20/31/29	0	1251 (1150)	6,1 [b]	A1	84,2 [b]	44,0 [b]	4342 [b]
R410A	**R32/R125 50/50**	**0**	**2088 (1920)**	**0,1 [a]**	**A1**	**71,3 [a]**	**49,0 [a]**	**6773 [a]**
R290 (propane)	-	0	3 (3)	-	A3	96,7 [a]	42,5 [a]	4083 [a]
R466A	R32/125/R13I1 49/11,5/39,5 [f]	~0 [f]	733 (696) g	0,3 [d]	A1 [f]	83,8 [f]	59,1 [f]	7123 [d]
R459A	R32/1234yf/1234z(E) 68/26/6	0	461 (461)	1,7 [b]	A2L	79,6 [b]	53,4 [b]	6087 [b]
R454B	R32/R1234yf 68,9/31,1	0	466 (467)	1,0 [a]	A2L	78,1 [a]	52,7 [a]	6293 [a]
R32	-	0	675 (677)	-	A2L	78,1 [a]	57,8 [a]	6966 [a]
R452B	R32/125/1234yf 67/7/26	0	698	0,9 a	A2L	77,1 a	52,2 a	6531 [a]

4.2.1 Properties of R134a and possible alternatives

According to [25], R134a was the first chlorine-free HFC refrigerant that was tested comprehensively. It is used for evaporation temperatures in the range of 0 °C and condensation temperatures of up to 85 °C. Available alternatives to R134a include the Low GWP refrigerants R1234yf and R1234ze(E) which are classified A2L. The other Low GWP refrigerants, also A2L, are either in development (R444A) or not yet available (R516A) [25]. The non-flammable options are characterised by significantly higher GWP values, starting with R515B (Solstice® N15 [30]) at a GWP of 293. R450A (Solstice® N13 [31]), R513A (OpteonTM XP10 [32]) and the in-development R456A [25] have a GWP in the range of 600-700.

Figure 4.3 depicts the saturation pressure of R134a (to be read from the left vertical axis) and the difference to saturation pressures of the alternatives (to be read from the right vertical axis) over the dew temperature. The left diagram shows the alternatives with GWP values below 150 and the right diagram the non-flammable alternatives.

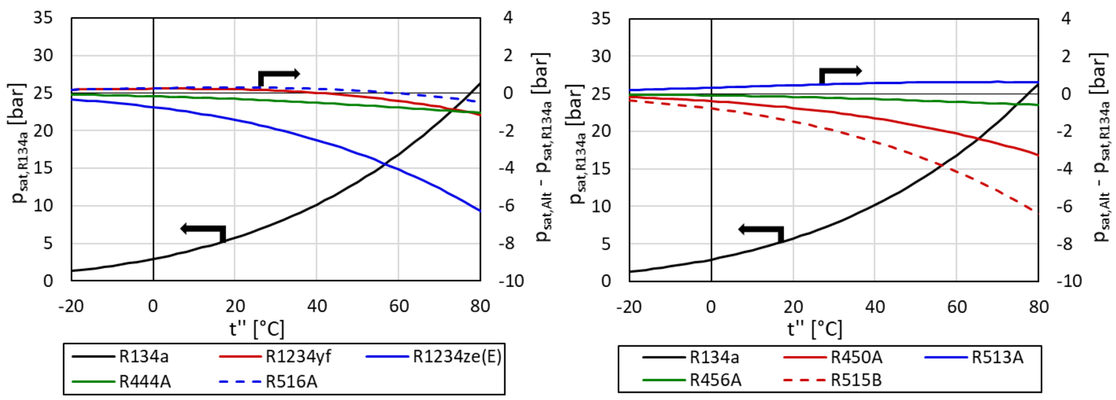

Figure 4.3: Saturation pressures of Low GWP alternatives to R134a (left) and non-flammable alternatives (right). Property data for R134a, R1234yf, R1234ze(E), R450A, R513A extracted from [27], data for R444A, R516A, R515B and R456A extracted from Refprop [28]

For the Low GWP alternatives it can be seen that R1234yf, R444A and R516A offer similar saturation pressures as R134a while the saturation pressure of R1234ze(E) is significantly lower. For the A1 classified alternatives, R513A and R456A have similar pressures while R450A and R515B have lower pressures.

The volumetric cooling capacity of the Low GWP alternatives according to Eq. 1 are depicted in Figure 4.4 (left). It can be seen that R1234yf, R444A and R516A offer similar volumetric cooling capacities than R134a while the capacity of R1234ze(E) is significantly lower (–23% at 0 °C). The non-flammable options are compared in Figure 4.4 (right). R513A and R456A offer similar capacities as R134a while R450A (–14%) and R515B (–25%) have significantly lower volumetric cooling capacities.

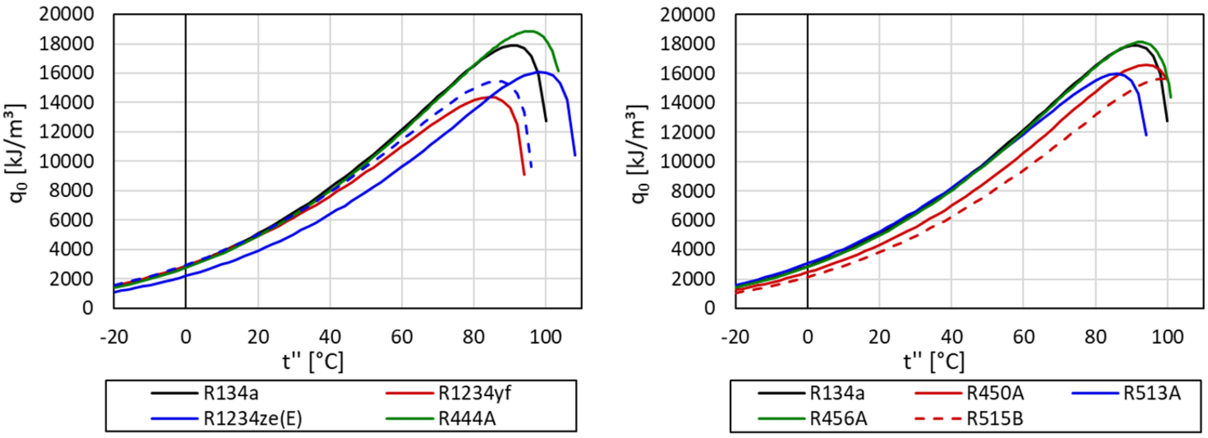

Figure 4.4: Volumetric cooling capacities of Low GWP alternatives to R134a (left) and non-flammable alternatives (right). Property data for R134a, R1234yf, R1234ze(E), R450A, R513A extracted from EES (2019), data for R444A, R516A, R515B and R456A extracted from Refprop [28]

4.2.2 Properties of R407C and possible alternatives

R407C is mainly used in heat pumps and normal refrigeration equipment, it is characterised by a relatively large temperature glide of 7,1 K at 1 bar, according to KKA (2011). The alternatives with GWP values below 150, R454C (OpteonTM XL20 [33]), R455A (Solstice® L40X [34], the not yet available R457A and the in-development R459B [25] are flammable (A2L). The not yet available R465A is classified A2. R448A (Solstice® N40 [35]), R449A (OpteonTM XP40 [36]), R449C (OpteonTM XP20) [37]) and the in-development R460B [25] are non-flammable, yet their GWP values are in the range of 1300.

Figure 4.5 compares the saturation pressure of R407C with alternatives having a GWP value below 150 (left) and non-flammable alternatives (right). The left diagram shows that R455A and R465A almost match the pressure curve of R407C. R454C and R459B deviate up to 4 bar in the considered temperature span and R465A has the largest deviations with a 6 bar lower saturation pressure at 80 °C. Regarding the non-flammable options, R449C matches the pressure of R407C, while R448A and R449A deviate up to 2 bar and R460B up to 4 bar.

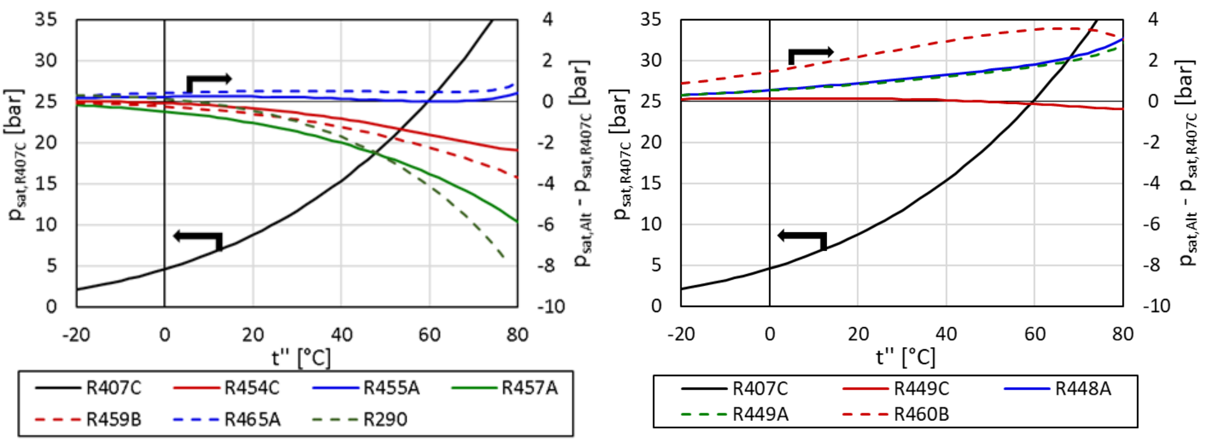

Figure 4.5: Saturation pressures of "Low-GWP" alternatives to R407C (left) and non-flammable alternatives (right). Property data for R407C, R454C, R455A, R448A and R449A extracted from EES (2019), data for R457A, R459B, R465A, R460B and R449C extracted from Refprop [28]

The volumetric cooling capacity of R407C and alternatives with a GWP below 150 are depicted in Figure 4.6 (left). R455A (+3% at 0°C), R454C (–3%) and R465A (+4%) are in good agreement with R407C, deviations are observed for R459B (–7%) and 457A (–11%). The non-flammable alternatives are compared in Figure 4.6 (right), with good agreement for R460B and R449C and larger deviations for R449A (+10% at 0°C) and R448A (+10%).

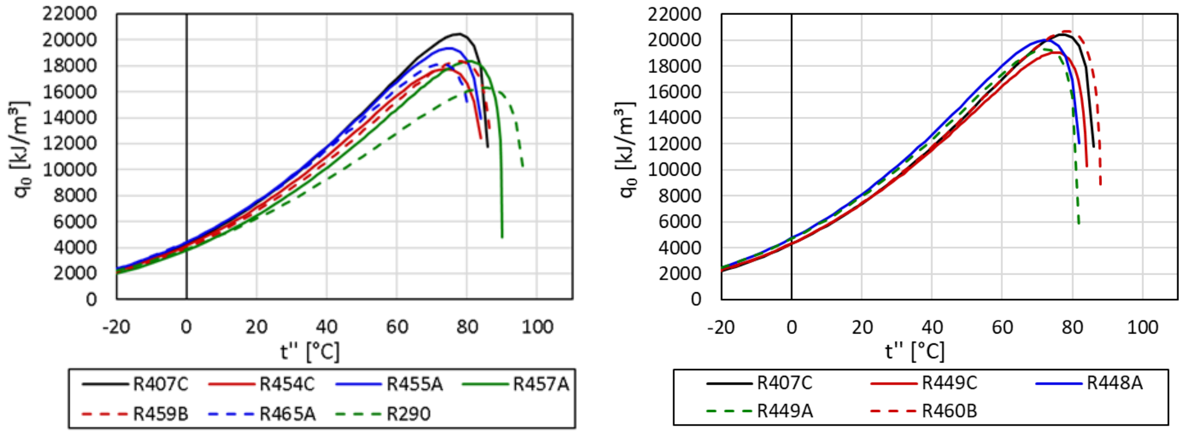

Figure 4.6: Volumetric cooling capacities of "Low-GWP" alternatives to R407C (left) and non-flammable alternatives (right). Property data for R407C, R454C, R455A, R448A and R449A extracted from EES (2019), data for R457A, R459B, R465A, R460B and R449C extracted from Refprop [28]

4.2.3 Properties of R410A and possible alternatives

R410A is used in heat pumps and in air conditioning systems, characterised by a small temperature glide (< 0,2 K) and relatively high pressure levels (25 bar at +40°C dew temperature), according to KKA (2011). The alternatives R454B (OpteonTM XL41 [38]), R32 and R452B (OpteonTM XL55 [39]) and Solstice® L41y [40]) as well as the not yet available R465A are flammable (A2L). R466A is the only non-flammable alternative but has a GWP of ca. 700. R290 (propane) is the only Low GWP refrigerant with a GWP of 3 but it is classified A3. [25] reports the application of R290 in small air conditioning units and heat pumps with rather small capacities. Due to its flammability, stricter charge limitations, safety measures concerning electrical installations and requirements regarding installation site need to be considered.

Figure 4.7 (left) compares the saturation pressure of R410A with the flammable (A2L) alternatives. It can be seen that R459A, R454B, R32 and R452B have a similar pressure level while the saturation pressure of R290 is almost 50% lower than R410A. Figure 4.7 (right) compares the saturation pressure of the non-flammable alternative R466A with R410 and shows good alignment.

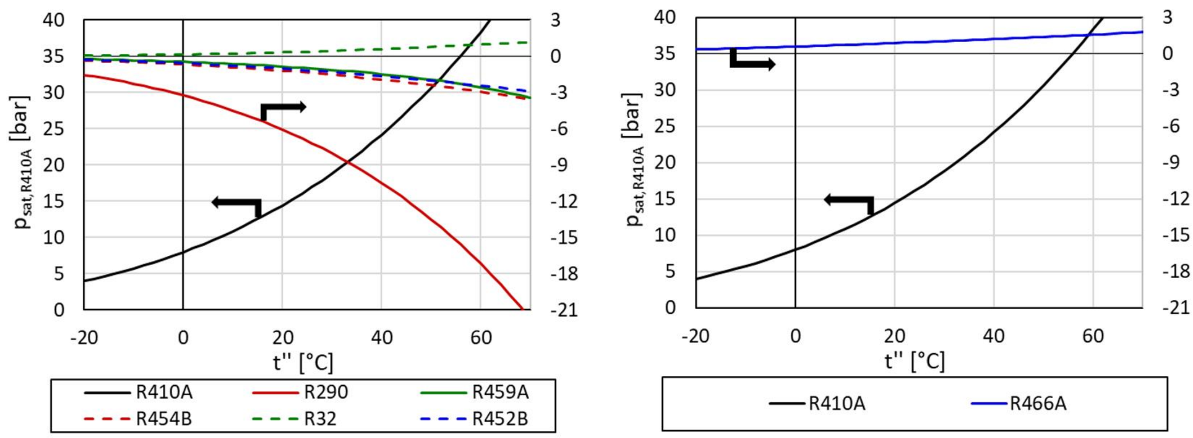

Figure 4.7: Saturation pressures of flammable alternatives to R410A (left) and the non-flammable alternative R466A (right). Property data for R410A, R290, R454B, R32 and R452B extracted from EES (2019), data for R466A and R459A extracted from Refprop [28]

Figure 4.8 (left) compares the volumetric cooling capacity of the flammable R410A alternatives. R32 (+3% at 0 °C) and R452 (–4%) are in close agreement with R410A, whereas R454B (–7%) and R459 (–10%) deviate more and R290 has a significantly lower cooling capacity (–40%). Figure 4.8 (right) depicts the volumetric cooling capacity of R466A compared to R410A and shows a slight deviation of 5% at 0°C.

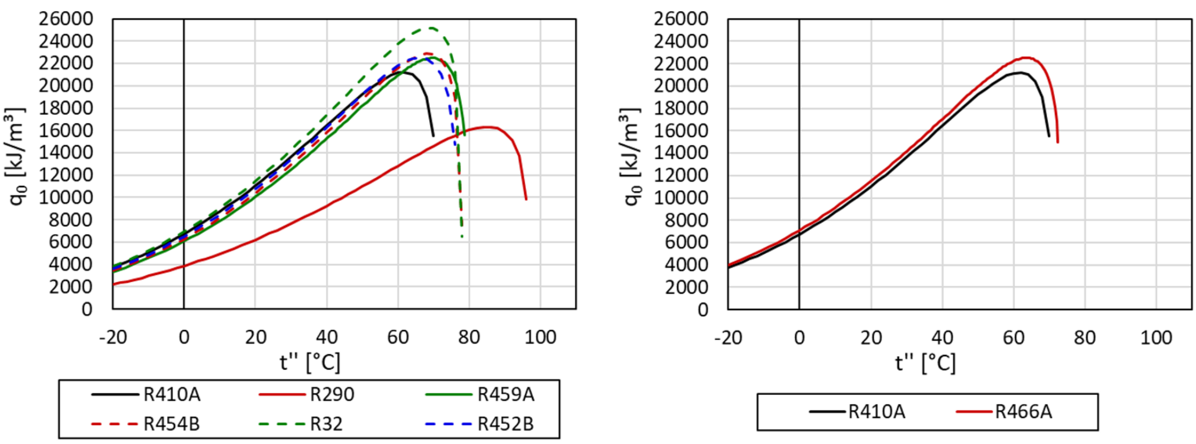

Figure 4.8: Volumetric cooling capacities of flammable alternatives to R410A (left) and the non-flammable alternative R466A (right). Property data for R410A, R290, R454B, R32 and R452B extracted from EES (2019), data for R466A and R459A extracted from Refprop [28]

4.2.4 Refrigerants in other applications

Applications like mobile heating and cooling and high temperature heat pumps are not in the direct scope of this Annex, yet these applications are practical examples for the utilisation of refrigerants with low global warming potential. An excerpt of refrigerants used in these applications is given in Table 4-2.

Table 4-2: Additional refrigerants covered in this Task report

ASHRAE-number	ODP	GWP_{100}	ASHRAE safety class	Application
R245fa	0	1030	B1	high temperature heat pumps
R1233zd(E)	0	4,5	A1	high temperature heat pumps
R600	0	3	A3	high temperature heat pumps
R744 (CO_2)	0	1	A1	mobile heating and cooling, heat pump water heaters
R717 (NH3)	0	0	B2L	commercial refrigeration, industrial heat pumps

4.2.5 Database screening

A more theoretical approach in order to determine potential substitutes for conventional safety refrigerants was performed by McLinden et al. (2017) [41] and Domanski et al. (2017) [42] by screening the PubChem database narrowing results applying desired properties, such as max. GWP, range of critical temperature, toxicity, stability and volumetric capacity. After this process, 21 from 60 million potential molecules remained. By allowing 6 resp. 7 additional chemicals that are of commercial interest or suitable for special applications, the final count is 27 resp. 28 molecules.

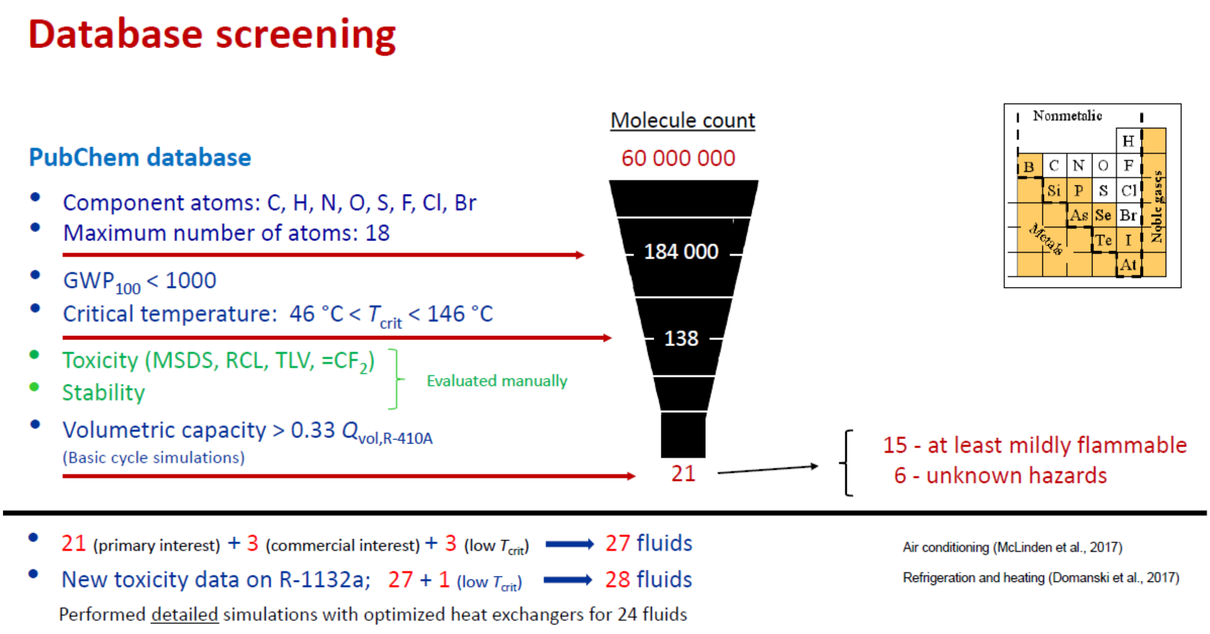

Figure 4.9: Screening of potential substitutes for conventional safety refrigerants [41], [42]

5. Currently Used Low GWP refrigerants in Domestic and Business Sector – R 290

The only Low GWP refrigerant currently used for domestic and business purposes is propane (R290).

Propane C_3H_8 is a byproduct of natural gas production and belongs to the safety class A3 which means highly flammable, but non-toxic. Its ODP is 0 and GWP is 3, which is far below widely used HFC or HCFC refrigerants.

R290 has been used as refrigerant in refrigeration for a long time and in household refrigeration, beside R600a (isobutane, also GWP = 3), it has a high market share. In the last years, it is also gaining more importance in the household heat pump sector as it can be seen from the market data presented before. Its performance characteristics are similar to those of R22 and R502. Propane is commercially available for many other purposes like heaters and barbeques, but as a refrigerant, purity requirements are higher.

R290 shows a lower system pressure drop and a higher heat transfer performance than typical HFC and HCFC refrigerants; therefore, only about half of the refrigerant charge is needed compared to systems with other refrigerants. Due to its flammability, it is not suitable as a substitute for HFC-based heat pump systems; regarding physical behavior it is rather comparable to R410A than to R134a and R407C, although some differences occur, see e.g. Figure 4.7 and Figure 4.8.

Most of the principal components like condensers and evaporators, safety, solenoid and shut off valves, pressure switches, thermistors, etc. are similar to those in HFC or HCFC refrigerant chillers. Compressors and expansion valves have to be adapted to R290 properties and should be fitted to chillers.

According to EN 378-1:2016 [07], the R290 charge is limited depending on the room type, the location and size of the machine, the occupancy category and whether the system is sealed, indirect or located in open air. For packaged open-air chillers there is no limit; still, many manufacturers limit the R290 to 25kg per circuit.

A leak detection system helps reducing the risk by collecting leaking refrigerant and immediately shutting off electric supply to the chiller.

The saturation vapour pressure and the volumetric cooling capacity of R290 compared to other refrigerants are shown in Figure 4.7 resp. Figure 4.8; further data is shown in Table 4-1.

For further information see e.g. [43].

6. Low GWP refrigerants in research projects and other heat pump applications

The following chapter gives an exemplary overview of research projects in Austria regarding Low GWP refrigerants and applications different from residential heat pumps.

6.1 Charge optimized R290 heat pump for retrofitting buildings

Due to the environmental approach of the research project GreenHP [44], the Low GWP refrigerant R290 was used in the 30kW air/water heat pump that was developed within the project. GreenHP addressed the integration of heat pumps into existing buildings in urban areas, where heat pumps must be compatible with pre-existing heating systems and must provide low installation and operation costs. Beside research activities regarding smart grid integration, the main research activities were regarding refrigeration technology: due to R290 flammability, the refrigerant charge was reduced to 65 g per kW thermal capacity by developing novel bionic distributors in the condenser and evaporator as well as by optimizing the oil sump reducing the amount of oil in the refrigeration circuit to 1 liter. The energy efficiency was improved by highly efficient heat exchanger fins, advanced fan design and a variable speed scroll-compressor prototype making use of Enhanced Vapour Injection. Hence, a high seasonal efficiency with an SCOP of 3.3 could be achieved [45].

6.2 Heat pumps and A/C systems utilizing R744 (CO2)

R744 is an environmentally benign refrigerant with zero ODP and negligible GWP. It is not flammable and not toxic, although concentration limits need to be considered. The properties of CO_2 differ significantly from other refrigerants, which need to be taken into consideration regarding component design. The relatively low critical temperature (31 °C) and high critical pressure (74 bar) call for a trans-critical operation of heat pumps, which makes a control of the high-side pressure necessary. Consideration of the heat sink temperature levels at the high-side pressure is necessary to optimize the efficiency [25].

According to [46], possible applications for CO_2 are heat pump water heaters and air heating systems.

In the Austrian R&D-project eco2jet [47], an air conditioning system with heat pump function for rail applications is being developed and shall be demonstrated in regular operation in a train of the Austrian railway operator ÖBB. The Institute of Thermal Engineering is a partner of the project consortium.

Another possible application for R744, which is gaining attention through the ban of R134a in the EU due to its high GWP, is air conditioning and heat pump systems for passenger cars. The future of this technology in the automotive sector is difficult to tell and will strongly depend on manufacturer’s experiences with the currently used R1234yf and R1234ze(E) [25].

6.3 R717 in large scale applications

R717 (Ammonia) is commonly used in large scale applications both for refrigeration systems as well as for heat pumps. One example application is the refrigerant plant with heat revocery at the poultry abattoir Titz in Feldbach/Austria. The refrigeration system with a cooling capacity of 2400 kW enables high-temperature heating (up to 95 °C), water pre-heating (up to 35 °C) and a brine-based heat distribution system (25 °C) with a total capacity of 1700 kW through heat recovery. In order to cope with peak loads and runtime delays, hot and cold reservoirs with 100 m³ and 10 m³ respectively are used [48].

6.4 High-temperature heat pumps using HFOs R1234ze and R1336-mzz(Z)

One possible application of R1234ze is high-temperature heat pumps. E.g., two large scale high-temperature heat pumps (Friotherm Unitop) installed at the steel mill Marienhütte in Graz/Austria recovering waste heat from the steel production and supply the district heating system. The heat pumps use two turbocompressors each, either in parallel or serial operation. In serial operation, a maximum supply temperature of 95 °C can be reached. The serial operation offers heating capacities of up to 3.3 MW at heat sink temperatures of 63/90 °C at the condenser. In parallel application, up to 5.75 MW can be reached at heat sink temperatures of 43/69 °C. The heat source temperatures at the evaporator are approximately 33.8/29 °C in serial and 33/25 °C in parallel operation [49].

Another research project in relation to Low GWP refrigerants is DryFiciency. A refrigerant for high temperature applications HFO-1336mzz-Z was used [50]. R1336mzz-Z is non-flammable, non-toxic and has a low GWP of approx. 2 [51]. The focus of the project is to elaborate technically and economically viable solutions for upgrading idle waste heat streams to process heat streams at higher temperature levels up to 160 °C. In the course of the project, two high-temperature industrial heat pump systems for waste heat recovery were developed and tested at two industrial sites in Austria (Agrana Stärke and Wienerberger). Building on the work done in DryFiciency, future heat pump installations can save approx. 80% of energy in the industrial drying processes, reduce CO_2 emissions by approx. 75% and reduce cost of production by approx. 20% per kg product.

6.5 High-temperature heat pumps using R600 (n-Butane)

Within the recent cooperative project "HotCycle" (FFG No.: 848892) [52] and the still ongoing project "TransCrit" (FFG No.: 865083) [53], the application of R600 in high-temperature heat pumps was investigated. R600 is characterised by a low GWP of 4 and is considered unproblematic regarding decomposition products when being released to the atmosphere. Due to its flammability, R600 belongs to the safety class A3 which requires additional measures to protect against fire and explosion hazards.

The scope of the project HotCycle covered the development and experimental investigation of a high temperature heat pump, enabling supply temperatures of up to 110 °C by utilizing a separating hood compressor.

Based in the results of "HotCycle", the focus of the project "TransCrit" is on the experimental investigation of a trans-critical R600 vapour compression cycle to achieve supply temperatures of over 150 °C. During the cycle development, the control of the high-side pressure and the degree of suction gas superheat were essential topics. Figure 6.1 (left) shows the hydraulic layout of the high temperature heat pump. The project is still ongoing and currently in the phase of experimentally investigating the high temperature heat pump. Measured COPs at trans-critical operation with a heat source inlet/outlet temperature of 60/55 °C, heat sink inlet/outlet temperature of 80/160 °C, an inverter frequency of 50 Hz and varying suction gas superheat and high-side pressure are depicted in Figure 6.1 (right). The maximum COP reached was 3,1 at a high-side pressure of 39 bar and a suction gas superheat of 20 K.

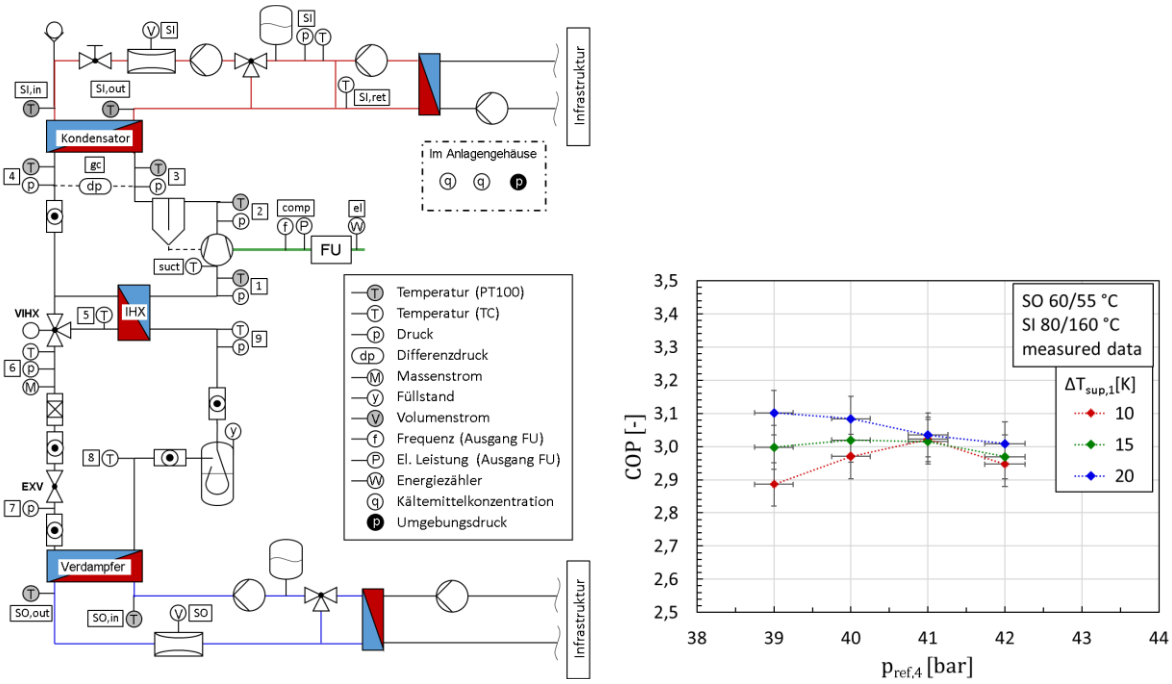

Figure 6.1: Hydraulic layout of the high temperature heat pump test rig developed and investigated through the course of the project "TransCrit" (left) and measured COP in trans-critical operation (right) [53]

7. Conclusions

Refrigerants with a GWP of 2,000 or even above still have a huge market share in the field of residential heat pumps. The only refrigerant with a GWP below 150 that is currently implemented in heat pumps for residential purposes is R290 – propane. There is even no sign that a Low GWP refrigerant in flammability class 1 will be ready to use in the near future. For flammable refrigerants, special restrictions and systemic requirements apply which are not feasible in every case. Therefore, for Task 2 it will be necessary to define exactly in which cases an elevated flammability is problematic and when this can be tolerated. In cases where flammability class 2L, 2 or 3 is not tolerable, a higher GWP threshold has to be considered.

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