Fit for Green Cooling

Module E: Environmental impacts

Author: Rolf Hühren, HEAT GmbH

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

On behalf of

Federal Ministry for Economic Cooperation and Development

Federal Ministry for the Environment, Nature Conservation and Nuclear Safety

Introduction to the Refrigeration & air conditioning training guide

The refrigeration, air-conditioning and heat pump (RACHP) sector will be facing many changes over the coming years. Many refrigerants in current use will be phased-out or phased-down in the close future under the Montreal Protocol and its Kigali Amendment due to their harm to the environment including ozone-depleting and climate-damaging properties. Additionally, the various systems' energy efficiency is becoming ever more important. For skilled workers in the RACHP sector, this is resulting in challenges as new technologies enter the market.

There are several risks associated with working in the RACHP sector. Ozone-depleting and climate-damaging refrigerants cause environmental harm when released into the atmosphere during operating and servicing. On the other hand, the personal safety of the skilled workers handling the equipment and refrigerants as well as the safety of the users of such equipment must therefore be ascertained. Dangers include intoxication, refrigerant burns, suffocation, fire and explosions as well as electrical faults which may lead to fires and electrical shocks or bad practice installations causing refrigerant leakages.

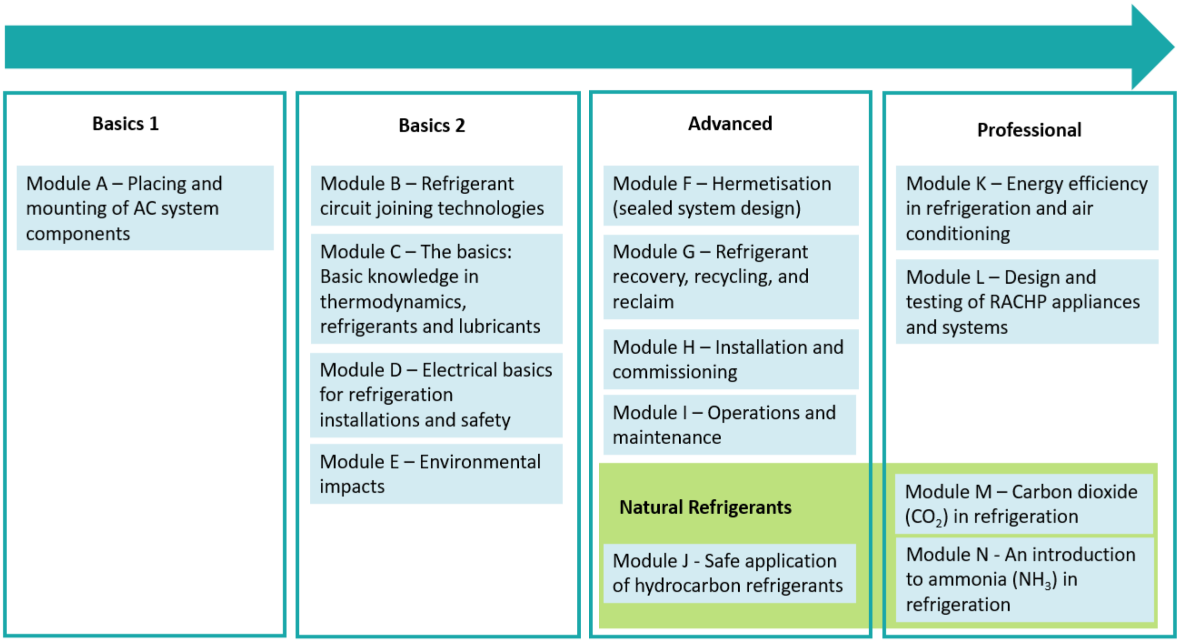
The reduction of greenhouse gases such as hydrofluorocarbons (HFCs) typically requires a combination of technology change, regulatory action and human capacity development. The technical characteristics of refrigerants change dramatically regarding their flammability, toxicity and/or operating pressure level with the transition from the predominantly used hydrochlorofluorocarbons (HCFCs) and (saturated) HFCs with high global warming potential (GWP) to climate friendly refrigerants, including natural refrigerants and a number of unsaturated HFCs (HFOs) with very low GWP.

This module on environmental impacts is part of a series of training modules on best practice guidelines in refrigeration and air conditioning, published by GIZ. These modules will form the basis for the qualified work of skilled workers and addresses the aforementioned challenges in the RACHP sector. The content of the module is based on international standards regarding the training of RACHP skilled workers as well as product and general RACHP safety standards. The set of modules range from basic knowledge necessary for skilled workers as well as more advanced qualifications involving the refrigerant circuit and professional level modules (see figure below), for example on energy efficient design or ammonia refrigeration. A good basis is necessary before starting on advanced modules.

The modules can be used to support a national quality infrastructure based on approved best practice codes and international standards. Essential instruments for its implementation include qualification, certification, accreditation, registration, monitoring and financial incentive schemes. The certification of skilled workers and companies is essential to sustainably increase competencies in the RACHP sector. Certification should always be linked to examination by an accredited institution and registration in a country database. Certification will be based on the assessment of previously determined skills of which an example is contained in the presented modules. The content of the modules is based on skills to be assessed based on standards ISO 22712 (draft status) and EN 13313: Refrigerating systems and heat pumps – Competence of personnel.

The following modules are available:

Module A	Placing and mounting of AC system components
Module B	Refrigerant circuit joining technologies
Module C	The basics: Basic knowledge in thermodynamics, refrigerants and lubricants
Module D	Electrical basics for refrigeration installations and safety
Module E	Environmental impacts
Module F	Hermetisation (sealed system design)
Module G	Refrigerant recovery, recycling, and reclaim
Module H	Installation and commissioning
Module I	Operations and maintenance
Module J	Safe application of hydrocarbon refrigerants
Module K	Energy efficiency in refrigeration and air conditioning
Module L	Design and testing of RACHP appliances and systems
Module M	Carbon dioxide (CO_2) in refrigeration
Module N	An introduction to ammonia (NH_3) in refrigeration



In addition to this handbook, further material for trainers is available, such as trainer manuals, PowerPoint presentations, training agendas and handouts.

Disclaimer

Reasonable efforts have been taken to ensure that the information or advice is reliable, correct, accurate and accords with current standards as at the date of publication. The information or advice contained in this document is intended for use only by persons who have had adequate technical training in the field to which the code of practice relates. The document has been compiled as an aid only, and the information or advice should be verified before it is applied by any person. The user should also establish the applicability of the information or advice in relation to any specific circumstances.

To the maximum extent permitted by law, the GIZ and its consultants and trainers:

1. disclaim all responsibility and all liability (including without limitation, liability in negligence) for all expenses, losses, damages and costs, whether direct, indirect, consequential or special you might incur as a result of the information in this publication being inaccurate or incomplete in any way, and for any reason; and

2. exclude any warranty, condition, guarantee, description or representation in relation to this publication, whether express or implied.

In all cases, the user should also establish the accuracy, currency and applicability of the information or advice in relation to any specific circumstances and must rely on his or her professional judgement at all times. The user is furthermore responsible to inform themselves about the national legislation and directives and to act accordingly.

Pictures or figures for this module have been provided by Rolf Hühren, HEAT GmbH, unless otherwise noted.

Symbols

The following symbols are used to structure the text and highlight important messages:

Incorrect uses or work processes are highlighted by a red x.

Correct uses or work processes are highlighted by a green check mark.

See chapter xxx

Textbox referring the reader to a different chapter

How to

Referring to instructions describing work routines

Safety relevant message

Message with direct relevance to flammable refrigerants

Other signs used in the document:

Electricity

Explosive materials

Asphyxiation

Black text boxes highlight specific topics or additional information.

Contents

Figures

Tables

Learning outcomes

In this chapter, you will get a brief introduction to refrigeration: How does it work, why is it so important to humankind, what are its impacts on the environment, and what significant policies were set to regulate the use of refrigerants? You will also get an overview of natural refrigerants, including their advantages, main uses and characteristics.

Detailed learning outcomes are described below:

Basics 2 level	
Knowledge & skills	1. Know about the general impact of RACHP technologies and the various sectors on the environment 2. Learn about the environmental impact of refrigerants 3. Acquire a common understanding of environmental influences such as ODP, GWP and CO2 equivalent 4. Learn about regulative and technical policies that influence the RACHP sector and how this influences participants' work now and in the future. 5. Know the relevant alternative technologies to replace or to reduce the use of fluorinated greenhouse gases and about their safe handling 6. Have a brief understanding of natural refrigerants and their applications for "Green Cooling" technologies 7. Understand the respective advantages and disadvantages of natural refrigerants

List of abbreviations

Acronym	Definition
AC	Air conditioner
CFC	Chlorofluorocarbon
COP	Coefficient of Performance
EU	European Union
EEA	European Environment Agency
GHG	Greenhouse Gases
GWP	Global Warming Potential
HC	Hydrocarbon
HCFC	Hydrochlorofluorocarbon
HFC	Hydrofluorocarbon
HFO	Hydrofluoroolefin
IPCC	Intergovernmental Panel on Climate Change
LCCP	Life Cycle Climate Performance
NCG	Non-condensable gases
ODP	Ozone Depletion Potential
ODS	Ozone Depleting Substance
RACHP	Refrigeration, Air-Conditioning and Heat Pumps
TEAP	Technology and Economic Assessment Panel
TEWI	Total Equivalent Warming Impact
UNFCCC	United Nations Framework Convention on Climate Change

E1 Introduction

Refrigeration is a process of removing heat from a location (surrounding air) or a substance to be cooled (e.g. rooms, refrigerators or water) to another place where the heat can be released (e.g. to the outdoor ambient). A refrigerant is a substance (heat transfer media) that is used in this process to absorb or release latent heat, typically using phase change.

While refrigerators are a relatively modern invention, the approach of keeping food fresh by storing it at lower temperatures has been known for thousands of years (3000 B.C. the Egyptians and Mesopotamians used natural ice for food preservation). Until the 1800s, this was done by using natural means, such as water, air and ether.

In 1755, the Scottish physician and chemist William Cullen succeeded in producing ice by evacuating a partially water-filled vessel. This creation of "artificial cold" is described in the literature as the year of birth of refrigeration.

After the invention of “artificial” cooling, a variety of refrigerants was used (see Figure 1). With the exception of water, air and carbon dioxide, they were all either flammable, toxic, or both until the 1930s.

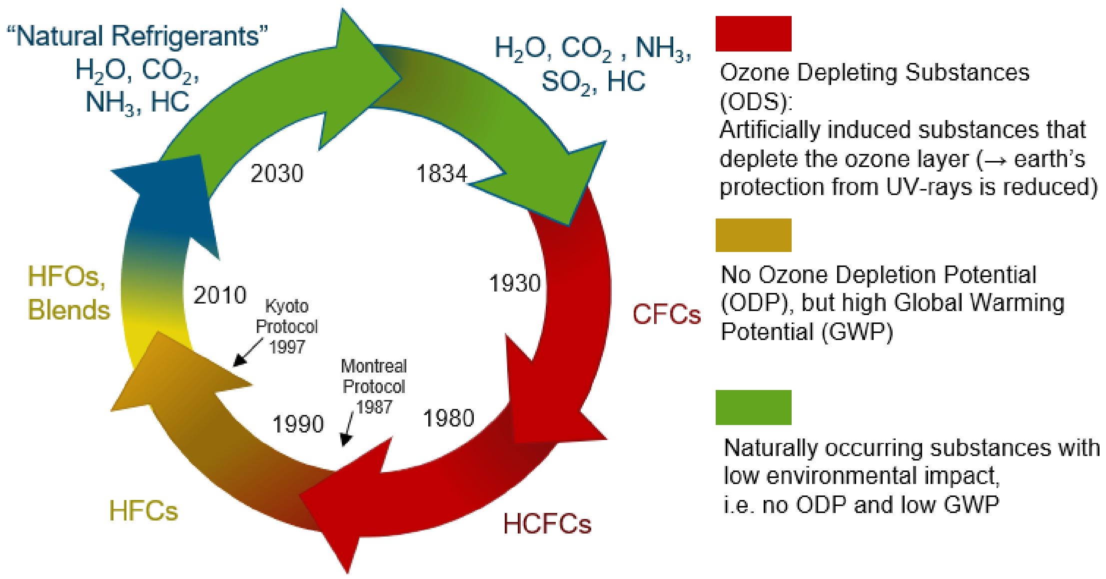


Figure 1 Refrigerants – historical development (Source: SECOP)

☛ Module C on basic refrigeration introduces the basic thermodynamic processes in refrigeration and handles refrigerant substances in detail.

Today, refrigeration has many applications in the industrial, commercial and domestic sectors. With increasing global temperatures, especially cooling needs in growing urban areas will further accelerate.

Refrigeration appliances consume a large amount of energy worldwide every year. Only in Germany, 71,000 GWh are needed for refrigeration every year. The following diagram shows which areas of refrigeration technology consume the most energy.

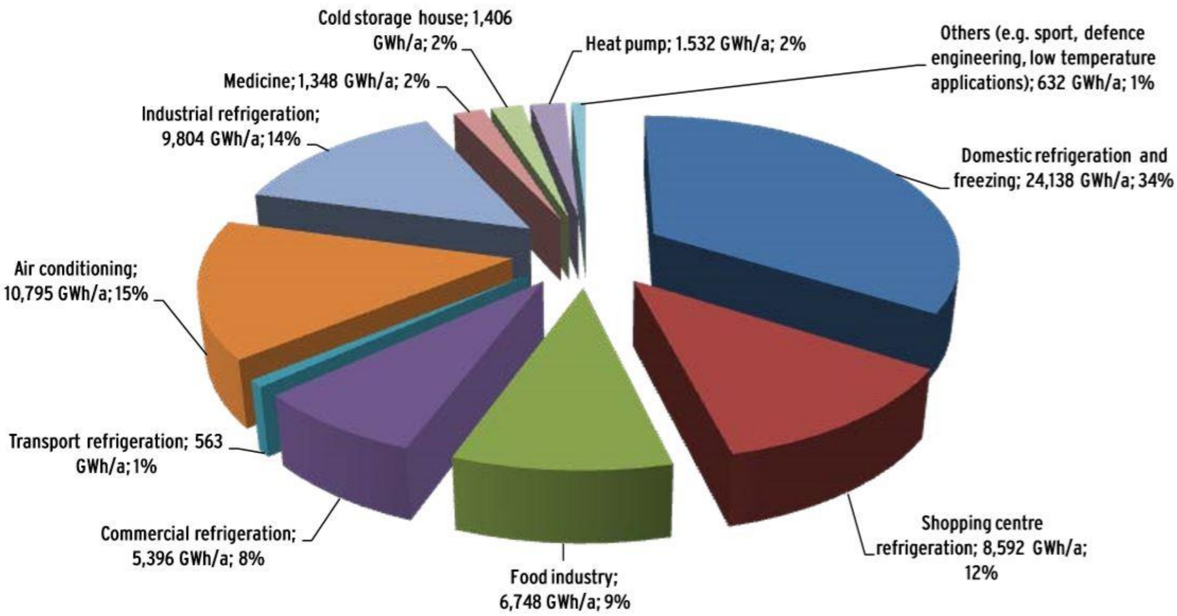


Figure 2 Share of refrigeration electrical energy demand of various industrial sectors (Source: VDMA, 2011)

There is growing concern as both the increased energy consumption and the current use of refrigerants have led to environmental problems. Directly through the release of ozone-depleting or climate-damaging chlorinated and/or fluorinated refrigerants, and indirectly through the energy and resources used in their production, transport, operation and disposal. Refrigeration systems have become a major challenge for sustainable development. The three billion refrigeration systems worldwide consume 17 % of global electricity (IIR, 2015).

The efficient use of natural refrigerants is a promising approach to help meeting the challenge of a growing demand for refrigeration on one hand and the urgent need to limit its impact on the environment on the other hand.

The ideal refrigerant (or working fluid, heat transfer media), whether natural or synthetic, should combine the following characteristics (RTOC, 2014):

1. Performance (capacity and efficiency)
2. Safety (including flammability and toxicity aspects)
3. Availability of the refrigerant
4. Zero Ozone Depletion Potential (ODP)
5. Impact on Climate Change (reduced direct and indirect impact, reduced energy-related emissions)
6. Impact on product and servicing costs
7. Skills and technology required to use
8. Recyclability
9. Stability and materials compatibility

No currently available refrigerant can fulfil all these requirements or score perfectly in each category. The choice of fluid for each specific application will therefore be a compromise between the different categories. For every application, the appropriate refrigerant has to be carefully selected, considering the installation location, requirements of the operator and environmental issues.

The requirements for the refrigerants of the future are basically that they have no ozone depleting potential (ODP) and no or very low global warming potential (GWP). ODP and GWP will be further explained in Chapter G2. Due to their high GWP values, synthetic refrigerants will not be able to comply with these requirements. Contrary to natural refrigerants, which have no ODP and zero or low GWP. Hence, these refrigerants are considered an excellent environmentally friendly alternative for the future. At the same time, natural refrigerants are not “safety refrigerants” as they have properties such as flammability or toxicity. In order to use these refrigerants safely, some additional skills are required. Refrigeration systems working with natural refrigerants also need additional safety devices.

E2 Environmental impacts of refrigeration and related policies

E2.1 Environmental impacts of refrigeration

The recent development of refrigeration in the 20^{th} century was assisted by the discovery of chlorofluorocarbons (CFCs) as “safe” refrigerants in 1930 by Thomas Midgley and his team. CFCs are non-toxic and non-flammable and were soon used in all application types of refrigeration and air-conditioning technologies as well as many other areas, such as aerosol cans and blowing agents. Today’s ubiquitous availability of refrigeration and air conditioning, especially in motor vehicles, the commercial sector and private households, is largely influenced by the invention of CFCs.

E2.1.1 Ozone depletion and the Montreal Protocol

Equally important was the discovery of the dangerous impact CFCs have on the earth’s atmosphere, namely their contribution to ozone depletion, by Rowland and Molina in 1974. CFC R11 is one of the most potent chemicals responsible for creating the ozone hole in the stratosphere over the Southern Hemisphere. A single chlorine atom released by CFCs can last for up to 100 years in the atmosphere and can destroy 100.000 ozone molecules (EPA, 2018). Therefore, in 1987, the Montreal Protocol was concluded to protect the ozone layer from further depletion (see Chapter G2.2). It regulates the gradually phase-out of harmful substances to the ozone layer, including CFCs, which have been banned since 1 January 2010.

The industry was quick to replace CFCs with products using hydrochlorofluorocarbons (HCFCs), the latter having lower ODPs, but still high GWPs. Since 2007, the phase-out of HCFC refrigerants is also addressed under the Montreal Protocol. HCFCs will be phased out for production until 2030.

Partly as a direct replacement for CFCs, partly as a replacement for HCFCs, a third class of fluorinated chemicals was introduced, the hydrofluorocarbons (HFCs). These have no ozone depletion potential, but a global warming potential (GWP) (see Chapter G2.1.2) still up to several thousand times higher than CO_2. The latest amendment to the Montreal Protocol, the so-called Kigali Amendment (2016), will require the phase-down of this group of chemicals, primarily used in RACHP systems and foam insulation, in the near future.

Ozone Depletion Potential

The Ozone Depletion Potential (ODP) of a chemical compound is the relative amount of degradation to the ozone layer it can cause, with the CFC R11 being fixed at an ODP of 1.0.

Ozone-depleting substances (ODS) are substances that damage the earth's ozone layer in the upper atmosphere. ODS include chlorofluorocarbons (CFCs) such as R12 and R502, hydrochlorofluorocarbons (HCFCs) such as R22, R123, R142b and drop in blends such as R408A. HCFCs are still used as refrigerants in many Refrigeration, Air Conditioning and Heat Pump (RACHP) equipment. ODS are defined in Annex A of the Montreal Protocol.

Ozone depletion increases the amount of UVB radiation that reaches the Earth's surface and leads to the following negative impacts for life on earth:

- Effects on human health: more cases of skin cancer; UVB has been linked to the development of cataracts, a clouding of the eye's lens
- Effects on plants
- Effects on marine ecosystems
- Effects on biogeochemical cycles

E2.1.2 Global warming and the United Nations Framework Convention on Climate Change (UNFCCC)

It was further discovered that several refrigerants (including CFCs, HCFCs and HFCs), contribute to global warming as they have a high global warming potential (GWP). In the framework of the Kyoto Protocol that entered into force in 2005, the consumption of hydrofluorocarbon (HFC) refrigerants with high GWPs has to be reported. The Kyoto Protocol is an international treaty, which was adopted as the first addition to the United Nations Framework Convention on Climate Change (UNFCCC) that committed its signatories to develop national programs to reduce CO_2 emissions in order to lower the presence of greenhouse gases (GHG) in the atmosphere.

Global Warming Potential

The Global Warming Potential (GWP) is a relative measure of how much a given mass of greenhouse gas is estimated to contribute to global warming. It is calculated over a specific time horizon, arbitrarily over 100 years, but sometimes also over 20 or 500 years. The GWP is expressed relative to carbon dioxide, with a GWP = 1. The higher the GWP value, the more a substance will contribute to global warming.

The global warming potential of many refrigerants is regularly revised by the Intergovernmental Panel on Climate Change (IPCC) with new findings about the effect of CO_2 on global warming and the behavior of the substances in the atmosphere.

The lifetime of many HFCs is much less than 100, their main impact on the climate will therefore be on a much shorter time horizon. The average GWP20 for HFCs is 94 % greater than the GWP100 average. Hence, the GWP20 metric better reflects the true potency of HFCs during their actual time in the atmosphere (Greenpeace, 2012).

Figure 3 shows several refrigerants and their respective ODP and GWP.

Refrigerants (common examples)		ODP	GWP (time horizons of 100 years)
CFCs	R11	1	7,100
HCFCs	R22	0.055	1,700
HFCs	R507A	0	3,985
	R404A (R125+134a+143a)	0	3,800
	R410A (R32+135)	0	2,000
	R134a	0	1,300
HFOs	R1234yf	0	6
	R1234ze	0	4
	R290 (Propane)	0	3
	R600a (Isobutane)	0	3
Natural refrigerants	RC270 (Cyclopropane)	0	n/a
	R744 (Carbon dioxide)	0	1
	R717 (Ammonia)		<1

Environmental impact — Fluorinated — Non-fluorinated

Figure 3 ODP and GWP for commonly used refrigerants (Source: GIZ Proklima, based on data from IPCC, 2013)

E2.1.3 Persistent degradation product

Just like CFCs, HCFCs and HFCs, the newest class of synthetic refrigerants, unsaturated HFCs (uHFCs) also known as HFOs (hydrofluoroolefins), will again be responsible for introducing a persistent compound into the environment. Contrary to its predecessors, uHFCs (HFOs) have no ODP and a low GWP. However, their degradation product TFA (trifluoroacetic acid) has no known degradation pathway and will accumulate in water bodies, plants and soils. It is phytotoxic, i.e. toxic to some plants, and its long-term effects are not yet known.

Many uHFCs (HFOs) are also flammable and/or have toxicity implications and yield dangerous decomposition products when they burn. For example, the release of hydrogen fluoride from R1234yf, that is now starting to be used in mobile air conditioning, is endangering human health, adding concerns for rescue personnel and drivers in case of releasing the flammable refrigerant. The production process is typically much more energy intensive than for conventional (saturated) HFCs and, in addition, various ODS are used as feedstock. This makes them also more expensive than other refrigerants with prices unlikely to drop much.

The Rio Declaration on Environment and Development of 1992 states that: “Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation” (UN 1992). It urged states to apply this precautionary approach in case the impact of a substance on the environment is not fully understood yet.

E2.1.4 Looking ahead: Green cooling technologies

Today, industry is facing two main options regarding the future use of refrigerants. Companies could either move to unsaturated HFCs or HCFCs (so-called “HFOs”), which have a lower GWP but unknown impacts on the environment (see G2.1.3). Alternatively, they can opt for natural refrigerants.

Natural refrigerants

Natural refrigerants are not ozone-depleting and have no or negligible GWP.

Natural refrigerants were partly used in refrigeration processes until the mid-20th century. While some substances like ammonia have been in continuous use for the last century, others like carbon dioxide and hydrocarbons were “rediscovered” more recently as efficient options for refrigeration.

Natural refrigerants often have higher toxicity, flammability or high operating pressure. Therefore, their use requires additional training for technicians.

In addition to the selection of a suitable refrigerant, the design of the entire refrigeration system has a decisive influence on energy consumption. The efficiency of a refrigeration system is considerably more influenced by the overall concept (up to 50 %) than by the choice of the refrigerant (TEAP, 2018).

Most recently, the total greenhouse gas emissions during the equipment lifetime (Figure 4) has gained increased attention, demanding that reducing the negative impact from refrigerants released to the atmosphere would need to go hand in hand with a reduction in energy consumption. The move towards higher efficiency at the equipment or building level is a complementary concept to the avoidance of energy use and waste in absolute terms (increased eco-sufficiency). Reducing the use of mechanical equipment altogether by increased use of traditional cooling methods, the use of passive cooling or shading, or by influencing human behaviour for their operation are exemplary ways of following this concept for cooling applications.

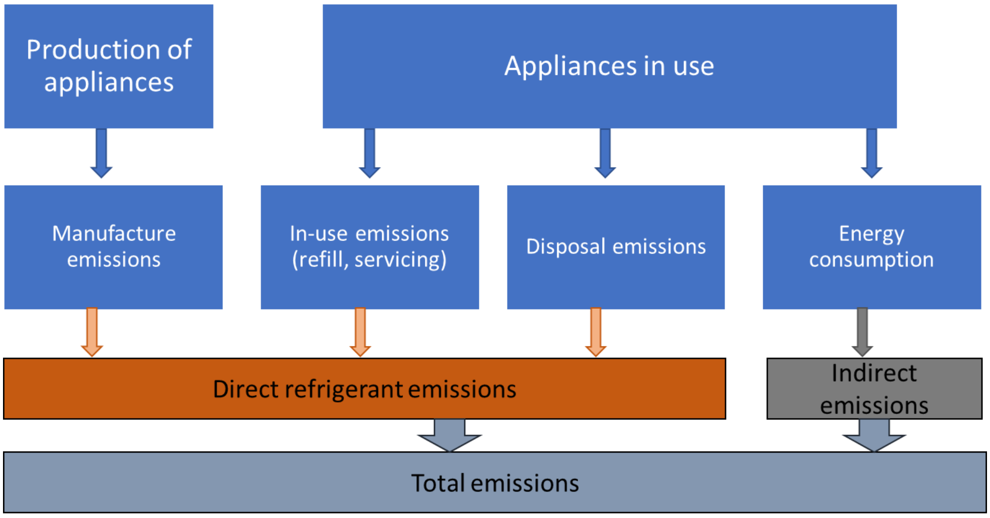


Figure 4 Emissions of RACHP equipment (Source: HEAT GmbH)

Emissions and energy efficiency

In the context of refrigeration and air conditioning, greenhouse gas emissions caused by refrigerants when released to the atmosphere are called “direct”, because they have a direct impact on global warming. “Indirect” emissions are caused by energy consumption during production, transport, operation and disposal of RACHP systems. Over the lifetime of RACHP equipment, both direct and indirect emissions lead to the total climate impact, often expressed with the Life Cycle Climate Performance (LCCP) or the Total Equivalent Warming Impact (TEWI).

Increased energy efficiency of cooling systems and reduced overall cooling needs do not only save the consumer or operator money, but they relieve the often-strained energy supplies and avoid black-outs, which can have a negative impact on the development of competitive industries and services. Energy efficiency also reduces the need for additional investments in energy infrastructure, which can be a huge financial burden to less developed countries.

☛ Module K handles all relevant aspects related to energy efficiency

Equipment with both, maximised energy efficiency and use of natural refrigerants, and thus, with minimised environmental impact, is termed “green cooling technologies” in this training guide. Green cooling technologies offer long-term alternatives for almost all types of systems and appliances in the RACHP sectors.

Switching from ozone depleting and climate harming fluorinated substances to natural refrigerants in energy-efficient systems and applications is often referred to as “leapfrogging” (see Figure 5). Finding opportunities to leapfrog could prevent countries and industries from having to phase new sets of fluorinated gases in and out again as international agreements become stricter over the coming years.

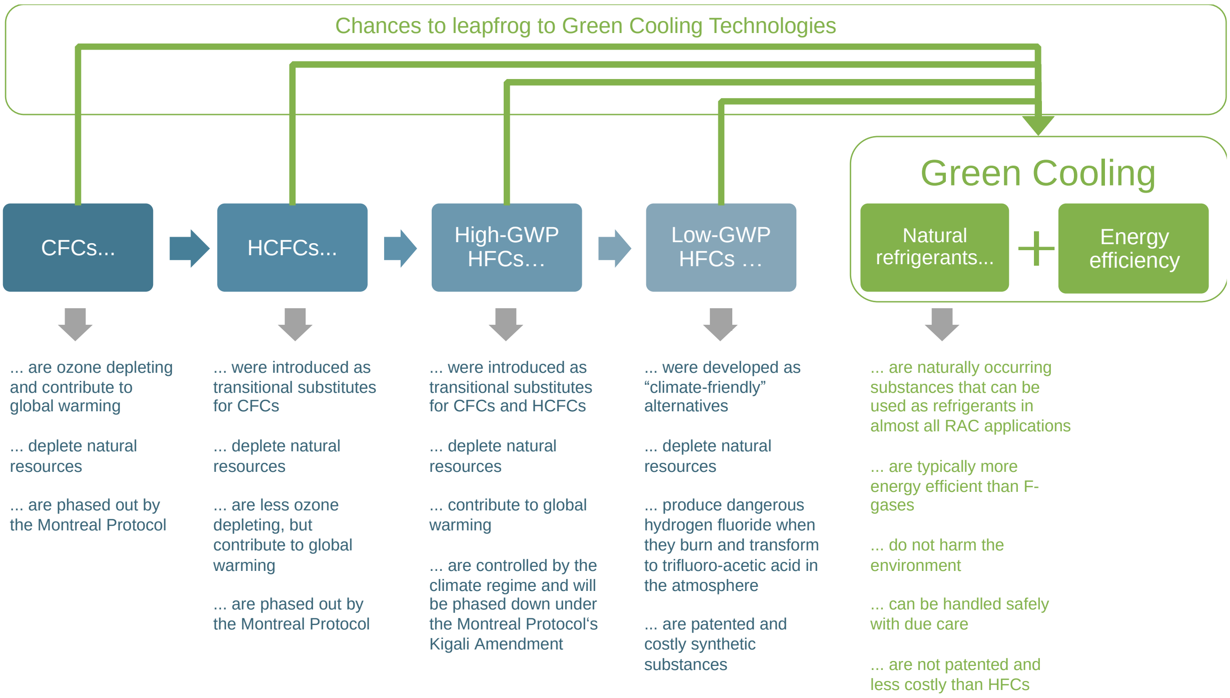


Figure 5 Leapfrogging to green cooling technologies (Source: HEAT GmbH)

E2.1.5 Total Equivalent Warming Impact (TEWI)

With TEWI, a calculation method has been developed with which the effects on the greenhouse effect during the operation of refrigeration systems can be individually assessed (TEWI = Total Equivalent Warming Impact).

The following box shows a common formula for calculating the TEWI characteristic value, in which the respective areas of influence are subdivided accordingly.

The TEWI has three parts, which are added to calculate the total value.

$$TEWI = GWP \times L \times n + GWP \times m \times [1-\alpha_{rec}] + n \times E_{anno} \times \beta$$

L	leakage rate per year (kg/a)
n	system operating life in years (a)
m	charge of refrigerant (kg)
α_{rec}	recovery/recycling factor from 0 to 1
E_{anno}	energy consumption per year (kW/a)
β	CO_2 emission factor of power generation (kg/kWh)

As several of the assumptions and factors in this calculation method are usually specific to an application in a particular location, the TEWI allows only a comparison at one specific place (e.g.France, Germany, or elsewhere) and comparisons between different applications or different locations are not suitable. The TEWI calculation is important at the design stage or to support a retrofit decision (EN 378-1, Annex B).

More information on Green Cooling technologies can be found at www.green-cooling-initiative.org and https://cooltechnologies.org

E2.2 Policy regulations

E2.2.1 The Montreal Protocol

The Montreal Protocol on Substances that Deplete the Ozone Layer was agreed on in 1987 to prevent the further destruction of the earth`s ozone layer. It has been ratified by all countries worldwide. The Montreal Protocol phases out the consumption and production of the different ODS in a step-wise manner, with different timetables for developed countries (referred to as "Article 2 countries") and developing countries (referred to as "Article 5 countries"). There has been a worldwide ban on CFCs since 2010. HCFCs, initially used as substitutes for CFCs, have been forbidden in most Article 2 countries since 2010 but are still widely used in Article 5 countries where they must be phased out by 2040 (see Figure 6).

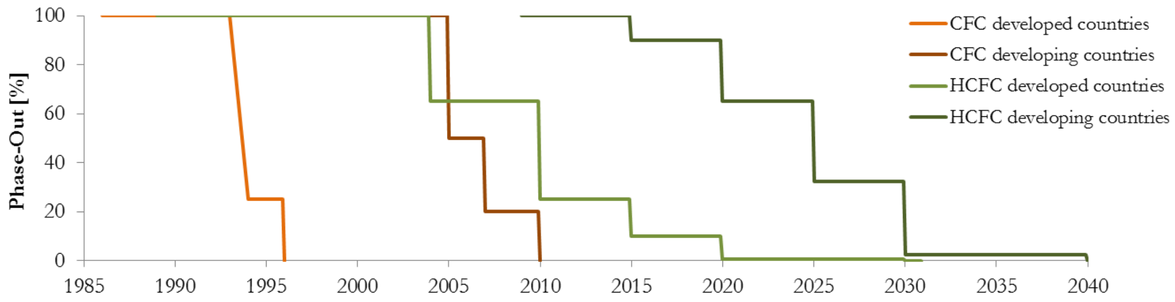


Figure 6 CFC and HCFC phase-out schedules for developed and developing countries according to the Montreal Protocol (Source: HEAT GmbH)

Since 1989, the Montreal Protocol has undergone several revisions, the last one in 2016 in Kigali. The Kigali Amendment entered into force in 2019 and integrates the third group of high-GWP gases into its global framework: hydrofluorocarbons (HFCs). Hence, the Amendment defines an HFC phase-down schedule for Article 5 countries and Article 2 countries. For most Article 5 countries, HFC consumption will be phased down to 20% of the baseline[2] by 2045 (Figure 7). This requires countries to make yet another switch from high-GWP HFCs to low-GWP substances (including natural refrigerants), or directly leapfrog from ozone-depleting substances to low-GWP synthetic or natural substances, without introducing high-GWP HFCs, such as R134a and R404A.

The Kigali Amendment has set a milestone for climate change mitigation. Even though HFC emission reduction is part of the Kyoto Protocol to UNFCC since 2005, binding obligations or phase-down schedules were never set.

[2] A5 Countries Group 1 (all A5 countries except of GCC countries, India, Iran, Iraq and Pakistan): baseline = medium consumption of years 2020-2022 and 65% baseline of HCFC component.

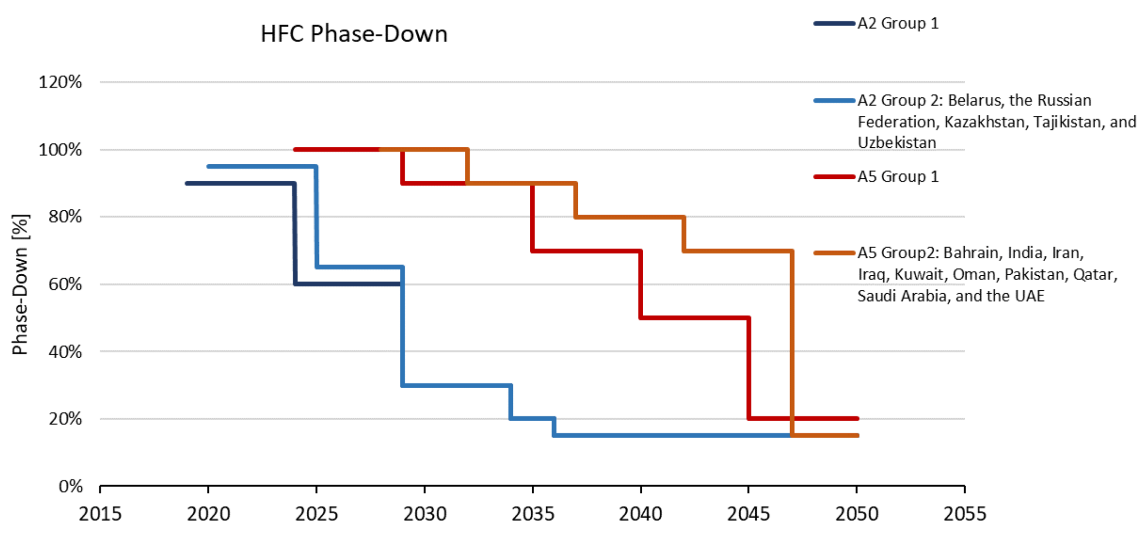


Figure 7 HFC phase-down according to the Kigali Amendment of the Montreal Protocol (Source: UNEP (2016), graph by HEAT GmbH)

Table 1 Phase-down schedule for A5 and A2 parties for HFC refrigerants according to the Kigali Amendment of the Montreal Protocol

	Article 5 Parties				Non-Article 5 Parties (A2 Parties)			
	Group 1		Group 2		Group 1		Group 2	
	Main group		Bahrain, India, Iran, Iraq, Kuwait, Oman, Pakistan, Qatar, Saudi Arabia, United Arab Emirates		Main group		Belarus, the Russian Federation, Kazakhstan, Tajikistan, Uzbekistan	
Baseline years	2020, 2021 & 2022		2024, 2025 & 2026		2011, 2012 & 2013		2011, 2012 & 2013	
Baseline calculation	Average production/ consumption of HFCs in 2020, 2021, and 2022 plus 65% of HCFC baseline production/consumption		Average production/ consumption of HFCs in 2024, 2025, and 2026 plus 65% of HCFC baseline production/consumption		Average production/ consumption of HFCs in 2011, 2012 & 2013 plus 15% of HCFC baseline production/consumption		Average production/ consumption of HFCs in 2011, 2012 & 2013 plus 25% of HCFC baseline production/consumption	
Freeze	2024		2028		N/A		N/A	
Reduction Step 1	2029	10%	2032	10%	2019	10%	2020	5%
Reduction Step 2	2035	30%	2037	20%	2024	40%	2025	35%
Reduction Step 3	2040	50%	2042	30%	2029	70%	2029	70%
Reduction Step 4	2045	80%	2047	85%	2034	80%	2034	80%
Reduction Step 5	N/A	N/A	N/A	N/A	2036	85%	2036	85%

The success of the Montreal Protocol can be seen in the significant reduction in the consumption of ODS that has been achieved since 1986 (Figure 88).

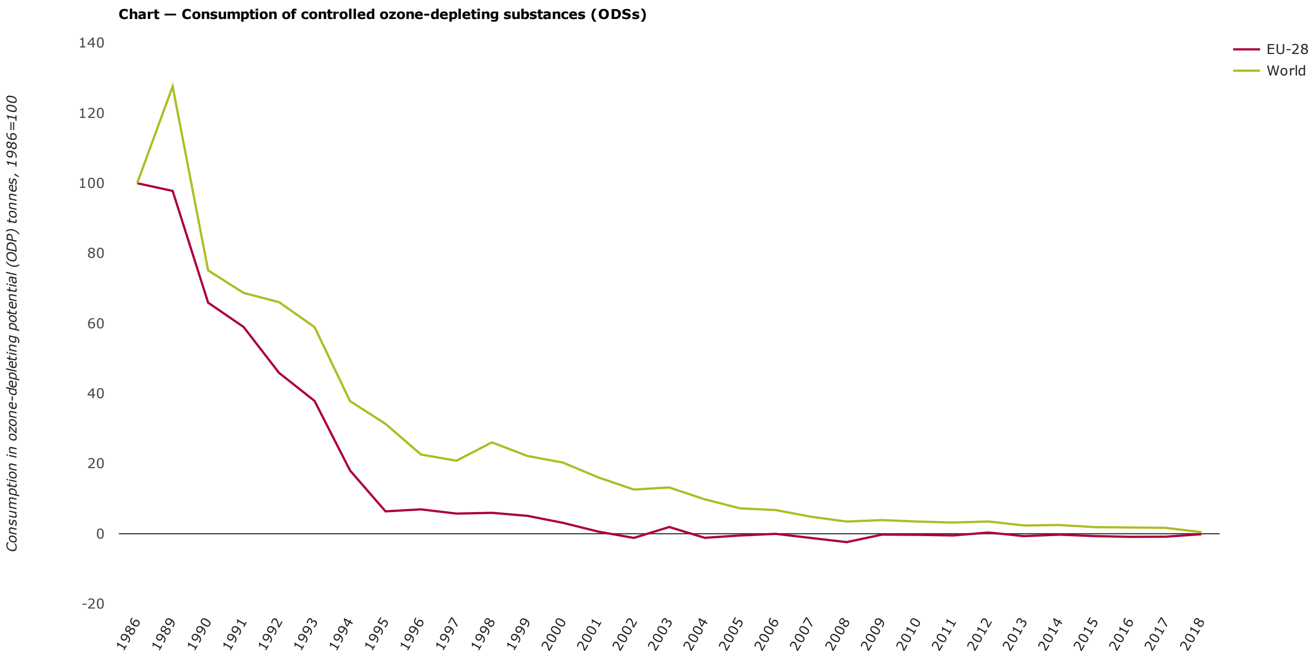


Figure 8 Global and European consumption of ODS since the year 1986 (Source: EEA, 2019)

E2.2.2 European Union

ODS regulation

The dominant ODS Regulation in place is EC 1005/2009. The key requirement of that regulation is the phasing-out of ODS. The virgin ODS refrigerant (R12, R502, R11) for maintenance and servicing of RACHP equipment has been banned since the end of 2009. A ban on the use of all (i.e. virgin, recycled and reclaimed) ODS for the maintenance or servicing of existing RACHP equipment is in place since 1 January 2015.

The EU F-gas regulation

Some countries and regions have already introduced laws restricting the use of HFCs overall or in specific sectors. In the EU, HFCs are already being phased down to 21% of current levels by 2030 thanks to the F-gas Regulation (Regulation EU N° 517/2014). The Regulation not only limits the total amount of most important F-gases that can be sold in the EU from 2015 onwards, but also bans their use in those sectors where less harmful alternatives – often natural refrigerants – are readily available. These sectors cover domestic refrigerators, commercial refrigeration for supermarkets, industrial refrigeration or air-conditioners. To prevent HFC emissions from existing equipment, leakage checks and proper servicing and recovery of the gases at the end of the equipment's lifetime are required.

The EU Mobile Air Conditioning Directive (Directive 2006/40/EC) is another EU policy tool to restrict HFC use. In passenger vehicle ACs, refrigerants with GWPs of more than 150 are prohibited.

E3 Natural refrigerants – an overview

Natural refrigerants are substances that occur naturally in the environment. Natural refrigerants are composed of the elements hydrogen, oxygen, carbon and nitrogen and include hydrocarbons, carbon dioxide, ammonia, water and air (also called “the natural five”).

Table 2 Natural refrigerants: The natural five

Refrigerant		Chemical structure	Refrigerant nomenclature
Hydrocarbons	propane	C_3H_8	R290
	propene	C_3H_6	R1270
	isobutane	C_4H_{10}	R600a
Carbon dioxide		CO_2	R744
Ammonia		NH_3	R717
Water		H_2O	R718
Air		N_2, O_2, Ar, CO_2, others	R729

The strong advantages of natural refrigerants are that they have zero ODP, and a zero or negligible GWP. For example, the GWP value for R717 is 0; R744 as the reference value for all other refrigerants has a GWP of 1; and the group of hydrocarbons have a direct GWP between 2 to 3. As part of the natural biogeochemical cycles, natural refrigerants do not form persistent substances in the atmosphere, water or biosphere. Table 3 presents a summary of characteristics of natural refrigerants.

Table 3 Characteristics of natural refrigerants

Refrigerant	Refrigerant Number	Chemical Formula	GWP (100 years)	ODP	Normal boiling point (°C)	Critical temperature (°C)	Critical Pressure (bar)	Safety group	Molecular weight (g/mol)
Ammonia	R717	NH_3	0	0	-33.34	132.4	114.20	B2L	17.03
Carbon dioxide	R744	CO_2	1	0	-78	31.04	73.77	A1	44.00
Propane	R290	C_3H_8	3	0	-42.1	96.7	42.48	A3	44.10
Isobutane	R600a	C_4H_{10}	3	0	-11.7	134.7	36.40	A3	58.12
Propylene	R1270	C_3H_6	2	0	-47.6	92.42	46.68	A3	42.10
Water	R718	H_2O	0	0	100	373.95	217.70	A1	18.02
Air	R729	$N_2/O_2/Ar/CO_2$	0	0	-192.97	-140.53	37.85	A1	28.97

Lower flammability & toxicity (B2L) | Higher flammability (A3) | Very high pressure (A1, R744) | Vacuum (A1, R718)

E3.1 Hydrocarbons

Hydrocarbons (HCs) are ideal as refrigerants as they are miscible with common refrigeration oils and as their critical temperature is relatively high (R290 = 96.7°C; R1270 = 92.4°C; R600a = 134.7°C; compared to R22 = 96°C). In general, R600a, R290 and R1270 can be considered as the most prevalent hydrocarbon refrigerants, as well as several HC blends and ethane (R170). Pure hydrocarbon refrigerants exhibit relatively good efficiency (coefficient of performance) due to their favourable thermodynamic and transport properties (such as ratio of discharge to suction pressure, low liquid density, high specific heat, high thermal conductivity, low viscosity, etc.). Because of their lower molar mass/density, the refrigerant charge for a given cooling capacity tends to be much lower (a half or less) than with fluorinated refrigerants. However, all hydrocarbon refrigerants are highly flammable and thus necessary safety precautions need to be implemented.

👉 See Module J Chapter 5 on safety precautions for flammable refrigerants.

The most commonly used hydrocarbons, propane and isobutane, are compatible with standard refrigeration materials and oils. One exception is propene (propylene), which is not compatible with neoprene. Consequently, special O-rings must be used with this refrigerant.

Many hydrocarbons have successfully been used as refrigerants in industrial, commercial and domestic applications.

E3.1.1 Isobutane (R600a)

R600a has a low saturated vapour pressure: 5 bar at +40 °C, compared to 10 bar for R134a and 18 bar for R404A. The low mass flow results in low pressure losses and high efficiency of the compressors, allowing the compressors to have higher COP.

R600a has its greatest success as a refrigerant in today's more than 1000 million household refrigerators (RTOC, 2018). It has been shown that refrigerators can be safely operated with hydrocarbons. Modern refrigerators are more efficient than ever and are quiet in operation due to the R600a properties. R600a is increasingly used in smaller commercial refrigeration systems, including beverage coolers and water dispensers.

Greenfreeze – a success story

In 1992, Greenpeace commissioned ten prototypes of a "Greenfreeze" refrigerator for testing purposes with the East German manufacturer dkk Scharfenstein (later Foron). After a short research, design and construction period, in 1993, the first refrigerator was launched in Germany, proving that R600a and R290 (as a 50:50 mixture), although flammable, caused no problems in a household refrigerator (Morgan, 2018).

The campaign from Greenpeace put so much pressure on the traditional manufacturers (e.g. Bosch-Siemens, Liebherr, Miele, AEG, Electrolux, Bauknecht) that they decided to accelerate the introduction of R600a and to phase out the – at the time – recently introduced HFC R134a.

Also, in 1993 the company Danfoss Compressors (today Secop) introduced the first compressors for R600a. Today more than 700 million domestic refrigerators globally use R600a and most of the global production is based on R600a. The European domestic market even has a total penetration of hydrocarbon refrigerants for household fridges (Secop, n.d).

E3.1.2 Propane (R290)

Propane has similar saturated vapour pressure to R22 and R404A. The compatibility of propane with common materials used in RAC installations and heat exchangers is given.

Since 2000, international well-known manufacturers have offered compressors with R290. Using these new HC systems, energy savings of between 10 and 30 % have been observed. Industries that are used to handling flammable substances have always used R290 and R1270 as refrigerants, often with large charge amounts approaching several tonnes. Recently there have been more and more global corporations and manufacturers offering R290 and/or R1270 as a refrigerant in commercial systems, commercial stand-alone units as well as heat pumps and air-conditioners.

First Blue Angel eco-label for R290 split AC

Air conditioners are designed to control the thermal comfort of living and working rooms and are especially used in those countries that regularly experience high outdoor temperatures. With rising income in many hot countries, the number of residential air conditioners is increasing rapidly and a large share of electricity consumption is caused by ACs.

If it is not possible to avoid the use of ACs by using appropriate construction measures, environmentally friendly ACs are necessary. This can be reached by energy efficient units with natural refrigerants.

Midea's "All Easy Series" residential split system air conditioner using R290 refrigerant has been awarded the German environmental label "Blue Angel". The Blue Angel Certification is owned by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety. The world's oldest ecolabel represents the highest standards for energy efficiency, health and environment-friendliness of home appliances. Criteria included are ultra-low GWP, high energy efficiency, low noise, and stringent material safety control (Blauer Engel, n.d).

E3.1.3 Application of hydrocarbon refrigerants today and in the future

Figures 9 and 10 illustrate the ease of application of hydrocarbons for the refrigeration and air-conditioning sectors.

Colours and relevance:

- Green – Application already available and state-of-the-art
- Orange – Application is possible, but barriers exist
- Red – Significant barriers for the application of natural refrigerants

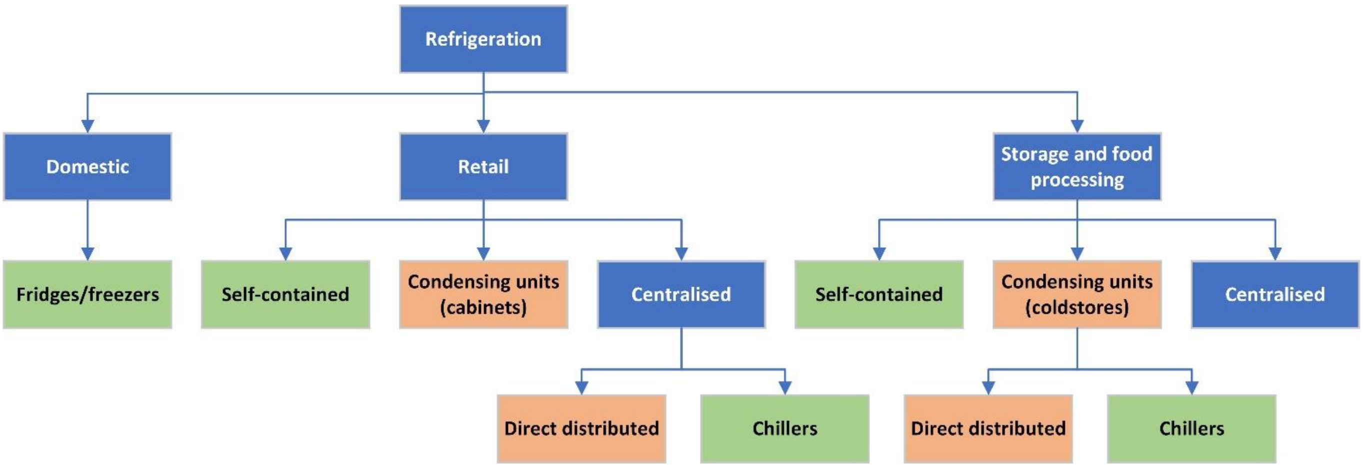


Figure 9 Ease of application of hydrocarbons for the refrigeration sector (Source: HEAT GmbH)

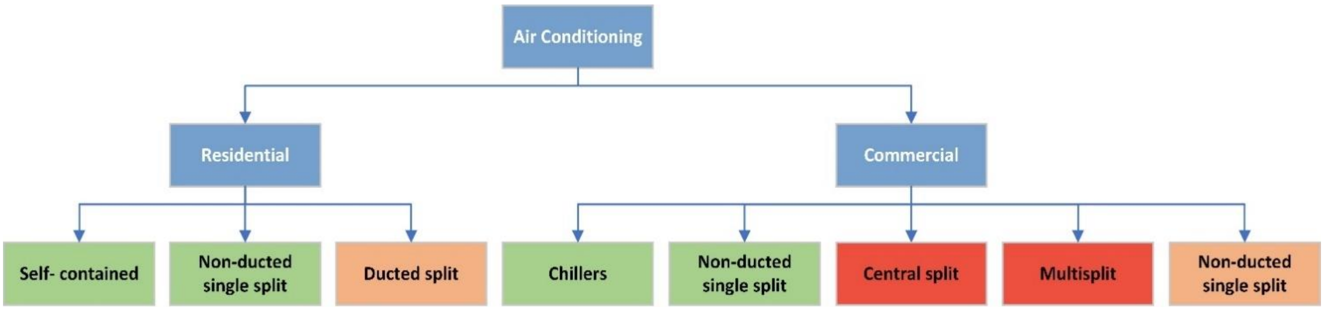


Figure 10 Ease of application of hydrocarbons for the air conditioning sector (Source: HEAT GmbH)

E3.2 Carbon Dioxide (R744)

What significantly differentiates R744 from common refrigerants are the greatly deviating working conditions, such as the restricted working range in subcritical systems. Due to its triple point, CO_2 cannot produce temperatures of approximately below -50 °C.

Carbon Dioxide offers numerous advantages:

- It has a favourable pressure ratio and the volumetric efficiency is better than other conventional refrigerants;
- Components such as the compressor and pipe diameters can therefore be much smaller, resulting in shorter defrost times, reduced material usage and system weight is generally reduced;
- Due to the high heat transfer coefficient the heat exchanger can be built relatively small. In addition, due to the low viscosity, relatively low pumping work is necessary in an R744 system. This is particularly advantageous for systems with a long network length (e.g., such as found in supermarkets and in direct evaporating systems for deep cooling).

R744 is most commonly applied in supermarket refrigeration systems, cold storage, and industrial, commercial and domestic heat pumps.

See module M on the safe application of carbon dioxide (CO_2) in refrigeration.

E3.3 Ammonia (R717)

Ammonia is one of the oldest refrigerants with the best thermodynamic properties of all refrigerants. It is the only natural refrigerant that is so efficient that industry has always used it. Also, from an environmental point of view, ammonia has the benefits of an ODP and GWP of 0.

R717 is lighter than air and thus leaks can be buoyant, making it easier to install on the roof.

In addition to the known applications in large industrial plants, ammonia is increasingly being considered in projects which in the past have been planned exclusively with synthetic refrigerants (e.g. in public buildings). All large exhibition halls in Germany were built with ammonia chillers for air conditioning. Banks, insurance companies and office buildings are also increasingly being climate-controlled with ammonia chillers. In addition, many modern airports no longer want to operate AC systems without ammonia plants, after risk analysis verified no greater threat to the public as with conventional refrigerants.

See module N on the safe application of ammonia in refrigeration.

E3.4 Water (R718)

Cooling by evaporation of water is well known and has always been used. Ice water or ice slush (slurry ice) systems that use other refrigerants to produce ice cream are also known and proven, although much research is still being done in this area. The water steam compression process offers the greatest potential, but also the biggest challenge.

Water as a refrigerant comes into consideration when large amounts of ice water or pumpable ice slush are needed (e.g. for the food industry, district cooling or cooling of mines). The biggest challenge to date has been the enormous volume of water vapour that requires the use of rather expensive turbo compressors. The large required pressure ratio requires the use of either axial compressors with a relatively small installation area and many stages, or even series-connected centrifugal compressors that are quite sensitive to load fluctuations and therefore require a fairly constant load. Since the operation takes place in deep vacuum, an absolutely hermetic (tight) system is required.

On the other hand, there is an energy saving potential of 25 % compared to today´s available R134a liquid chillers. Research projects with both radial and axial compressors are currently being carried out with prototypes in France and Germany.

E3.5 Air (R732)

Air can be used as a refrigerant in almost any application. Typically, energy advantages can be observed if applications require temperatures below -50°C.

Modern aircrafts flying at high altitudes are equipped with an air conditioning and pressurization system to provide a convenient environment for its passengers. In these systems compressors are coupled with the aircraft engine using the ambient air.

R732 is suitable for freezer applications from -40 to -80°C. In these systems, the expansion turbine is on the same drive shaft as a turbo-compressor. The energy generated during the expansion is used by the compressor, thus reducing energy consumption. It is for example used in Japan in ultra-low freezing applications for fish.

E4 Practical implications for technicians

Every skilled worker can reduce the environmental impact by properly planning installations and refrigerant use and following best practice techniques. The following chapter highlights some of these activities.

E4.1 Planning of the installation

Well planned and dimensioned RACHP equipment will reduce the environmental impact considerably over its lifetime. Very often, equipment is too big for its purpose. Proper dimensioning, for example by conducting a cooling load calculation will ensure that the unit is not using more energy than necessary. Depending on the climate zone and the anticipated use, units equipped with inverters can further contribute to reduced electricity consumption. This is especially the case when nights are cooler or there are distinctive seasons with cooler temperatures throughout the year.

☛ See module L on the calculation of cooling loads and other issues related to the design of RAC systems.

Choosing the refrigerant

As outlined above, many synthetic refrigerants have a negative impact on the environment through their ODP and their contribution to climate change, when they leak into the atmosphere. Choosing an environmentally friendly refrigerant, such as hydrocarbons, CO_2 and ammonia will have a huge impact on reducing these emissions.

Many suppliers offer the same equipment as well with conventional (fluorinated) refrigerants as with natural refrigerants. Make sure you have the appropriate training, tools and personal protective equipment before installing these units.

☛ Other modules provide detailed information:
- Module J on the on the safe application hydrocarbons
- Module M on carbon dioxide (CO_2)
- Module N on ammonia in refrigeration

E4.2 Good practice during installation and servicing

Proper installation and servicing of split AC units considerably support the efficiency and reliability of the equipment over its lifetime, while avoiding additional costs for electricity and spare parts. At the same time, it reduces safety risks by avoiding problems before they even occur or detecting issues at an early stage to prevent accidents. Where ‘traditional’ refrigerants are still in use, good practices are also necessary to substantially reduce environmental risks: i.e. the risk of harmful substances (either in terms of ozone depletion or global warming, or both) escaping uncontrolledly or accidentally into the atmosphere.

An efficient operation of RAC systems relies on regular servicing, including maintenance of the adequate refrigerant charge, and cleaning practices. A system will never run as smoothly and efficiently as under factory or testing conditions if it is not installed well and serviced at regular intervals. For example, in field trials in Europe, it has been found that maintaining the correct charge of refrigerant in ACs had an energy saving potential of 29.4 %. Cleaning heat transfer surfaces and filters (or replacing dirty filters) had an average 24.9 % energy saving potential. Maintaining the proper system control set points is another factor that could save up to 8.4 % of energy (Knight et al., 2010).

Important points to consider in order to avoid inefficient working of AC equipment are presented in Table 4.

Table 4 Points to consider in order to avoid inefficient working of AC equipment

Area of intervention	Points to consider
Building envelope	Solar gain reduction (shading, blinds etc.)
	Preferably shading on the building exterior
	If possible, modify vegetation to gain additional shading
	Avoid building envelope leaking by uncontrolled exchange of air
Planning stage	Define correct system size (for many cases systems are oversized (30 % >)
	Cooling load calculation can help to find optimal system configuration
	If applicable consider smaller system
	Choose correct location of outdoor and indoor units
	For chilled water installations, free cooling could be considered
	Consider the integration of occupancy sensors
Installation stage	Positioning of indoor unit and outdoor unit according to manufacturer's specification
	Do not sequence multiple outdoor units (mutual influence)
	Avoid air- leakage on pipework (ductwork)
	Check accurate positioning of return air filter
	Avoid restrictions in refrigerant transfer lines
	Avoid poor insulation of refrigerant and condensate pipes
	Check that controls are correctly positioned and adjusted
	Check that control sensors are placed correctly
Operational system	Avoid system operation when not required
	Do not operate air conditioning with open windows or passages of the building
	Ensure that manufacturer's user instructions are on site
	Maintenance contract should always be concluded with the user
Maintenance & Servicing	Avoid that systems set-points are too low (< = 22 °C)
	Maintain appropriate regular filter cleaning regime (user and service staff)
	Replace defective or worn functional parts promptly
	Execute regular refrigerant leakage testing
	Ensure the use of the correct type of refrigerant
	Do not overcharge the system with refrigerant
	Avoid that heat exchanger fins are blanked off, correct if necessary
	Avoid condenser corrosion or fouling, correct if necessary
	Avoid evaporator corrosion or fouling, correct if necessary
	Avoid lack of air flow through wrong fan rotation or damaged blades

Other modules provide detailed information:
- Module H on good practices in installation and commissioning
- Module I on good practices in servicing and maintenance
- Module J Chapter 11 on leakage testing
- Module B on joining technologies (brazing and pressing connections)
- Module K on energy efficiency

E4.3 Recovery of refrigerant and decommissioning of the equipment

Good practices in refrigerant management during an equipment's lifetime and at its end-of-life ensure environmental and personal safety, reduce emissions, optimize efficiency and performance of systems and accordingly save costs.

When appliances containing HCFCs or HFCs are decommissioned, due care needs to be taken to recover and dispose of the refrigerant in a legal and environmentally safe manner. Venting of ODS and HFCs (releasing them into the atmosphere) is not allowed. Hence, all ODS and HFC refrigerants must be recovered when old equipment is decommissioned and before entering the waste stream.

It is possible to recycle or reclaim used refrigerants and use them again (see box below for the definition of these terms).

Recovery: Recovery of refrigerant means removing a refrigerant in any condition from a refrigeration system and store it in an external container.

Recycling: Recycling means to reduce contaminants in used refrigerants following a basic cleaning process. This process may include separating of oil, removing of non-condensable *gases* (NCG) and using of devices such as filter-driers to reduce moisture, acidity and particulate matter.

Reclaim: Reclaim means the reprocessing of a recovered refrigerant in order to match the equivalent performance of a virgin substance, taking into account its intended use. The reclaim process may include distillation. Chemical analysis of the refrigerant will be required to determine that appropriate product specifications are met. Acceptable levels of contaminants (purity requirements) are specified in national or international standards for new product specifications (e.g. AHRI 700:2019). Reclaim usually implies the use of processes or procedures available only at a re-processing or manufacturing facility, such as a Reclaim Centre.

See Module G on recovery, recycling and reclaim of refrigerants.

Destruction: If the recovered refrigerant cannot be used anymore (e.g. because of impurities, lack of application possibilities/bans), **destruction**, e.g. in suitable incinerators, is the only way to prevent it from reaching the atmosphere.

Specialized facilities conduct destruction of refrigerants: e.g. incineration, reactor cracking, gaseous/fume oxidation, rotary kiln incineration, cement kiln, or radio frequency plasma. Destruction technologies are approved by the Technology and Economic Assessment Panel (TEAP) of the Montreal Protocol.

GIZ Proklima has also published a series of publications on ODS management, including a guideline on the manual dismantling of refrigerators and ACs, available at https://www.giz.de/en/worldwide/30797.html

Note: Even if refrigerant is recovered properly and stored in cylinders, leakage cannot be prevented entirely as, for example, cylinders could become damaged due to improper handling or storage. Damaged cylinder must not be used in any case!

See Module J Chapter 3 on the proper handling of refrigerant cylinders.

E4.4 Design and servicing features for natural refrigerants NH_3, CO_2 and HCs

The following table presents a comparison of features relevant for general servicing for the three most important natural refrigerants R717, R744 and hydrocarbons.

Table 5 Comparison of general servicing features for R717, R744 and Hydrocarbons

	NH_3 R717	CO_2 R744	HCs R290, R600a …
Weight in relation to air	Lighter	Heavier	Heavier
Refrigerant Purity	99.98 % min (3.8) Moisture < 200 ppm	99.995 % (4.5) Moisture < 10 ppm	99.5 % min (2.5) Moisture < 10 ppm
Gauges & Circuit Equipment	Stainless Steel R717 indication	High Pressure R744 indication	As for HCFC / HFC HC indication
Vacuum Pump	Stainless Steel ATEX, Vent Line	Regular Vent line	Regular ATEX, Vent line
Charging	Scale	Scale Pressure	Sensitive Scale (min. 2 gram resolution)
Tubing	Carbon steel, stainless steel	Copper, K65 (CuFe2P) Stainless steel	Copper
Leak Finding	Nose, Gas detector, Litmus paper, Sulphur stick, Bubble test, PPE	Gas detector, Bubble test, PPE	Gas detector Bubble test, PPE
Pressure test Leak Test	Nitrogen 4.0	Nitrogen 4.0 Trace Gas (N_2/H_2)	Nitrogen 4.0 Trace Gas (N_2/H_2)
Strength test PS x 1.1	Nitrogen 4.0 (Humidity ≤ 30 ppm)	Nitrogen 4.0 (Humidity ≤ 30 ppm)	Nitrogen 4.0 (Humidity ≤ 30 ppm)

E5 Bibliography

AHRI (2019) *AHRI Standard 700: Standard for Specifications for Refrigerants.* Retrieved November 19, 2020, from http://www.ahrinet.org/App_Content/ahri/files/STANDARDS/AHRI/AHRI_Standard_700_2019.pdf

Blauer Engel (n.d.) *Klimageräte*. Retrieved November 19, 2020, from https://www.blauer-engel.de/de/produktwelt/elektrogeraete/klimageraete#1410

EEA (2019) *Consumption of controlled ozone-depleting substances (ODSs)*. Retrieved 5 November, 2020, from https://www.eea.europa.eu/data-and-maps/indicators/production-and-consumption-of-ozone-3/assessment

EPA (2018) *Basic Ozone Layer Science.* Retrieved November 19, 2020, from https://www.epa.gov/ozone-layer-protection/basic-ozone-layer-science

Greenpeace (2012). *Greenpeace Position Paper. 32nd Meeting of the Open-Ended Working Group of the Parties to the Montreal Protocol*. Retrieved November 19, 2020, from: http://ozonecenter.kg/wp-content/uploads/2014/05/Greenpeace-Position-Paper-32nd-Meeting-of-the-Open-Ended-Working-Group-of-the-Parties-to-the-Montreal-Protocol.pdf

IIR (2015) *The Role of Refrigeration in the Global Economy, 29th Informatory Note on refrigeration technologies.* Retrieved November 5, 2020, from https://iifiir.org/en/fridoc/138763RTOC (2014) *Assessment report of the Refrigeration, Air Conditioning, and Heat Pumps Technical Options Committee.* Retrieved November 19, 2020, from https://ozone.unep.org/node/3313

Knight, I., Adnot, J., Alexandre, J., André, P., Assimakopoulos, M., Butala, V., Hitchin, R., Masoero, M., Spitzbart, C., & Wright, D. (2010). *HARMONAC - Harmonizing Air Conditioning Inspection and Audit Procedures in the Tertiary Building Sector. Energy Consumption in European Air Conditioning Systems and the Air Conditioning System Inspection Process – Final Report.* Retrieved November 19, 2020, from https://pdfs.semanticscholar.org/2e6a/0ee8989e794dba0b33f7233878b10186ccb3.pdf?_ga=2.203440208.1709216868.1579259792-1483634215.1579259792

Morgan, J. (2018). *How Greenpeace changed an industry: 25 years of GreenFreeze to cool the planet - Greenpeace International.* Retrieved 19 November 2020, from https://www.greenpeace.org/international/story/15323/how-greenpeace-changed-an-industry-25-years-of-greenfreeze-to-cool-the-planet/

RTOC (2018) *Assessment report of the Refrigeration, Air Conditioning, and Heat Pumps Technical Options Committee.* Retrieved November 19, 2020, from https://ozone.unep.org/sites/default/files/2019-04/RTOC-assessment-report-2018_0.pdf

Secop (n.d) *Hydrocarbons – Isobutane (R600a) and Propane (R290)*. Retrieved 19 November 2020, from https://www.secop.com/solutions/natural-refrigerants

TEAP (2018). *Report of the technology and economic assessment panel. Volume 5, Decision XXIX/10, Task Force Report on Issues Related to Energy Efficiency While Phasing Down Hydrofluorocarbons.* Retrieved November 5, 2020, from https://ozone.unep.org/sites/default/files/2019-04/TEAP_DecisionXXIX-10_Task_Force_EE_May2018.pdf

UNEP (2014) *2014 Report of the refrigeration, air conditioning and heat pumps technical options committee*. Retrieved May 1, 2020, from https://ozone.unep.org/sites/default/files/2019-08/RTOC-Assessment-Report-2014.pdf

UNEP (2016). *Final Report of Meeting of the Parties. Decision XXVIII/1, Annex 1.* Retrieved October 17th, 2018 from http://conf.montreal-protocol.org/meeting/mop/mop-28/final-report/SitePages/Home.aspx

United Nations (1992) *Rio Declaration on Environment and Development*. Retrieved November 19, 2020, from https://www.jus.uio.no/lm/environmental.development.rio.declaration.1992/15.html

VDMA (2011) *Energiebedarf für Kältetechnik in Deutschland*. Eine Abschätzung des Energiebedarfs von Kältetechnik in Deutschland nach Einsatzgebieten.

Standards referred to in this module:

Directive 2006/40/EC of the European Parliament and of the Council of 17 May 2006 relating to emissions from air conditioning systems in motor vehicles and amending Council Directive 70/156/EEC (Text with EEA relevance)

EN 378-1 Refrigerating systems and heat pumps - Safety and environmental requirements - Part 1: Basic requirements, definitions, classification and selection criteria

EN 13313 Refrigerating systems and heat pumps - Competence of personnel

ISO 22712 Refrigerating systems and heat pumps - Competence of personnel

Regulation (EU) No 517/2014 of the European Parliament and of the Council of 16 April 2014 on fluorinated greenhouse gases and repealing Regulation (EC) No 842/2006 Text with EEA relevance

Websites for further reference:

Cool Technologies (n.d.) Available at https://cooltechnologies.org

Green Cooling Initiative (n.d.) Available at www.green-cooling-initiative.org

Proklima, integrated ozone and climate protection (n.d). Available at https://www.giz.de/proklima