Appliances Guide
Get super-efficient appliances

bigEE

Technical background and design options to raise energy efficiency and reduce environmental impact of refrigerators and freezers

Authors
Claus Barthel
Thomas Götz

Created 12/2012

Index

1 Introduction and overview of design options

Many design options have been identified to increase energy efficiency and reduce the environmental impact of refrigerators and freezers.

The environmental impact of refrigerators and freezers (also called 'cold appliances') is mainly caused by their electricity consumption and their refrigerants and foaming agents.

Many technical design options to raise cold appliance energy efficiency already exist. Most of them are well known and their positive effect on electricity consumption is beyond question. While most have been partly implemented, a systematic approach to draft a super-efficient cold appliance is currently missing.

Cost is one reason. The purchase price of an extremely energy-efficient cold appliance would currently be too high to be offset by future electricity costs savings.

All electricity saving design options - independent of costs - are presented here, as costs are relative and can possibly be reduced in the future through economies of scale.

The main measures to improve the energy efficiency of cold appliances are:

- Improved insulation to reduce the cooling load
- Efficient compressors
- Evaporator/condenser and heat exchanger optimisation to improve the thermodynamic cycle
- Optimised electronic control and valve optimisation

The most important design options are listed in the following table. For the special conditions prevailing in the European Union around 2005, the table also includes the data for simple payback time (SPB , a measure of the riskiness of an investment) and net present value (NPV, a measure of the economic attractiveness of an investment). The actual value for a certain country and year will depend on parameters such as the electricity price, the size of an appliance and the cost of components.

The following chapters provide more detail on these and other design options. In these chapters, 'BAT' means 'Best Available Technologies', i.e. the most energy-efficient technologies commercialised today. 'BNAT' means 'Best Not yet Available Technologies'. These are options demonstrated to be technically feasible but not yet used in appliances on the market.

Appliance categories		**Refrigerators**		**Refrigerator-freezers**		**Upright freezers**		**Chest freezers**	
Option	**Technology option (description)**	**SPB (years)**	**NPV (€)**	**SPB (years)**	**NPV (€)**	**SPB (years)**	**NPV (€)**	**SPB (years)**	**NPV (€)**
a.1	vacuum insulated panels, door (area 70%, thickness 50%)	44.9	-38.45	31.7	-58.88	25.00	-40.94	22.8	-38.17
a.2	vacuum insulated panels, cabinet walls (50%)	35.9	-71.11	22.7	-67.76	22.3	-66.88	20.4	-61.35
a.3	+10-15mm insulation, door & cabinet walls	7.5	9.66	6.00	21.52	6.4	18.44	5.9	23.04
b*	low wattage brushless fan motor (4W AC fans)			7.6	4.67	6.7	6.88		
c (+g)	modified defrost with electronic temperature control and fuzzy logic, to be used together with Option g	32.9	-18.83						
d.1	increasing the surface area of the evaporator by 10-20%	9.0	1.17	7.6	4.67	8,9	2.03	4.9	8.41
d.2	increasing the surface area of the condenser by 5-10%	18.0	-2.11	9.1	0.72	10.7	-0.16	9.8	0.30
e	use of phase-change materials integrated into the heat-exchanger + compressor cycling optimisation	29.9	-16.33	15.1	-7.83	17.9	-10.47	16.3	-9.09
f.1**	higher efficiency reciprocating compressors (COP 1,5)	4.5	16.39	2.3	44.74	2.7	35.94	2.4	40.54
f.2**	optimisation of reciprocating compressors (highest efficiency of one producer)	8.3	7.55	5.2	36.91	6.2	25.47	5.6	31.45
f.3***	multi-speed and variable-speed compressors	13.5	-17.23	9.1	10.86	8.0	21.87	7.3	31.08
g (+c*)	Temperature control through electronic thermostats, to be used together with option c for no-frost models			22.7	-13.55	26.8	-15.31		
h (+g)	bistable solenoid valve (diverter valve) including electronic Control)			40.8	-33.55				

Table 1 Simple payback time (SPB) and net present value (NPV) at 15 years for the identified technological options applied to cold appliances standard base cases

Source: European Commission 2008

Refrigerants and foaming agents also raise environmental concerns. HCFC and CFC are used in most cold appliances. Both substances have a very high greenhouse gas potential but are easy to replace with natural refrigerants like hydrocarbons and CO_2. Therefore, chapter 7 presents options to reduce the environmental impact of refrigerants and foaming agents.

2 Improved insulation

Improved insulation is the main measure to reduce the electricity consumption of cold appliances

To keep food inside a cold appliance at a constant temperature, the compressor must compensate for the heat transfer into the cold appliance, which takes place through the cabinet. To save electricity, therefore, the first measure is to minimize this heat transfer and the resulting compressor electricity consumption by better insulation.
The main heat transfer into cold appliances occurs through the walls and the door (see table 2), whereas edge effect and other loads are responsible for up to 40 %.

Component	Percent of Total
Edge Effect Loads	**28.5%**
Heat gain due to conduction along the wall steel flange	5.3%
Heat input due to conduction along the door steel flange	7.1%
Heat conduction directly through the door gasket or seal	2,7%
Heat input due to conduction in the mullion region	1.7%
Heat input due to mullion region anti-sweat heater	7.7%
Heat input due to cabinet anti-sweat condenser tube	4.0%
Wall and Door Loads	**59.1%**
Miscellaneous Loads (heat inputs due to evap fan, defrost heaters, and compressors)	**12.4%**

Table 2 Overall cabinet loads (Source: US DOE 2010, 3-51)

2.1 Cabinet insulation

Most of the heat input into a cold appliance comes through the cabinet walls and doors. This can be reduced by the increase in thickness of foam and higher-quality insulation (such as vacuum insulated panels or gas-filled panels).

Best Available Technologies (BAT):

Increase thickness of insulation foam

In general, the insulation of cold appliances consists of Polyurethane (PU) foam. It has a conductivity of about 20 mW/m/K at 10°C (European Commission 2008, p. 463), for other insulations see (US DOE 2010, p. 3-47 or bigEE buildings guide). Total cabinet heat losses can be reduced by thicker insulation. This however, either reduces internal storage volumes or the external dimensions of the appliance.

(Fully) Vacuum insulated panels (VIPs)

With the application of VIPs as cabinet insulation, the thickness of the insulation can be reduced dramatically. This offers more design options; but on the other hand, VIPs are more expensive than PU foam.

VIPs basically consist of three parts: an airtight envelope membrane, a core insulating material holding the vacuum inside and preventing the membrane from collapsing and an absorber, also known as a “getter”. These are chemicals absorbing gases leaking through the membrane. By the lowering of pressure in the panel, conductivity values of the core material can be lowered to much better values compared to PU foam. Thus, maintenance of the vacuum over its lifetime is crucial. VIPs are fabricated in the their finally needed forms. In 2000, several commercial configurations of VIPs were already available with different core materials such as Polystyrene (PS), Polyurethane (PU), Silica Powder or Glass fibre. Heat conductivity varies from 9.7 mW/m/K (PU) to 2.4 mW/m/K (Glass fibre) – this means it insulates two to eight times better than conventional PU foam.

VIPs are currently used in certain architectural applications (especially, where there is not much space for thick insulations, like in dormers) and is as well BAT for refrigerators. As they are more expensive, in the cooling sector they are currently only used for door insulation where their low conductivity permits limiting the thickness of insulation, as a thick door is not user friendly.

Best Not yet Available Technologies (BNAT):

Gas-filled panels (GFPs)

The Lawrence Berkeley National Laboratory (LBNL) has developed this insulation technology. It consists of panels, which are filled with a low conductivity gas or air at atmospheric pressure. The panels can be inflated before transportation and assembly or thereafter. According to LBNL, they are easy to produce and especially promising for their intended application in niche areas.

This insulation technology is also very promising when considering its application in appliances — such as refrigerator doors — where space constraints due to user features or mechanical components would otherwise cause design problems. For example, high-performance, krypton GFPs (Gas Filled Panels) offer performance in just 1 cm of space that is equivalent to 2 cm of insulating with PU foam. Similarly, in cars, planes, and Recreation Vehicles, Gas Filled Panel technology holds the promise of thin, efficient, thermal insulation that functions as acoustic insulation as well” (LBNL 2006, US DOE 2011).

In 2008, the EU’s Eco-Design preparatory study for Lot 13 (household refrigeration appliances) qualified the conductivity/price ratio of this technology to be too low for usage in cold appliances (European Commission 2008, p. 462).

Aerogels

Aerogels are synthetic materials with a cell size of <50 nm. This physically leads to almost minimal thermal conductivity. Aerogels are the least heat conducting materials presently known. Despite intense research activities, production costs still remain very high, at about €1600/m^3.

This material is currently applied in the space industry and for other special uses. However, it is unlikely, that in the short term, costs will decrease – consequently, for mass application in cold appliances, it will probably remain inappropriate.

2.2 Increased door insulation

BAT

Better gaskets
Better door gaskets involve a trade-off between optimal insulation and ease of door opening. As the temperature difference causes aerial density differences, optimal insulation leads to low pressure in the cabinet and renders door opening harder. This is especially relevant for freezers. However, special handles have been designed facilitating opening by releasing a small gasket first, so as to part release the pressure difference before opening the whole door.

Anti-Sweat heaters
Condensation from room humidity may be a problem at certain room temperatures, especially on freezer doors/gaskets. To prevent sticking, extra heating may be necessary. Some producers use electrical resistance heaters, but to avoid additional energy consumption the better option is to pass the warm refrigerant discharge pipe through the parts concerned.
Safe to say, special attention should be paid to avoid extra heat loads into the cabinet. Careful positioning and design can optimise the performance (European Commission 2008, p. 464).

Improved design method for Through-the-door features
Mainly in the US, fridge/freezers are common which provide ice/cold water by Through-the-door (TTD) features. This is an additional heat leakage source in the door. In 1995, a study by the US Department of Energy showed, that by “improved design methods” of through-the-door features like ice dispensers, overall energy consumption can be decreased (US DOE 2010, p. 3-52).

BNAT

Additional gasket
Obviously, an additional gasket as an inner door seal can further reduce the heat leakage into the cabinet. However, due to temperature differences between the insulation regions, ice can form between the gaskets, which may reduce their effectiveness significantly. This, along with increased costs, is probably the reason why industry has not applied this option so far (US DOE 2010, p. 3-51).

2.3 Metal casing: reduction of “edge effect”

The typical cold appliance has an outer metal case. Total cabinet heat load is not only transferred radially but also along the metal shell (“edge effect”). The EU Eco design preparatory study for Lot 13 mentions up to 12% total cabinet heat load by this effect (European Commission 2008, p. 461).

3 Evaporator/condenser and heat exchanger optimisation

Evaporator/condenser and heat exchanger size should be optimized for low electricity consumption

BAT

Increased evaporator/condenser surface area

Increasing the heat exchange area of both the evaporator (by 10-20%) and the condenser (by 5-10%) can provide efficiency gains, which pay back economically in 6-18 years (depending on the model and other design choices, see European Commission 2008, p. 577) and at an optimum when their area is about 45% above the base-case area, as ADEME (2000) showed. However in practice, unlimited increase is not possible and in most cases constrained to 20% or less of base-case models (European Commission 2008, p. 478).

BNAT

Increased evaporator/condenser heat exchange capacity

Enhanced fins and/or tubes can achieve improved heat exchanging capacity. In 1995, a study carried out by DOE estimated the possible overall energy reduction potential due to these improvements was about 1-2% (US DOE 2010, p. 3-58).

Certainly, improvements can be realised by micro channel heat exchangers, electro hydrodynamic enhancement and the adoption of phase-change materials. Electro hydrodynamic technologies involve the use of high voltages for enhancing heat exchange capacities – which means safety issues for domestic appliances will remain unresolved.

Optimised chimney effect for static condensers

The condenser may be either simply located openly at the back of the appliance (hot-wall condenser) or as a housed condenser with a fan (forced convection condenser). Static, hot-wall condensers may be better designed for a more efficient airflow and thus increased heat transfer.

The forced convection type can provide greater heat transfer effectiveness, but there may not be sufficient space. For this design fans are needed. Condenser fans are typically axially designed which poses some efficiency-design questions. A US company) has developed a patented special fan design, which reduces fan energy consumption by 23% and overall energy consumption by 4% (US DOE 2010, p. 3-60).

Low-wattage fans to increase heat transfer at the evaporator and condenser

Fans may also be used to increase the heat transfer of the standard condenser design, whereby any efficiency gains from improved convection have to outweigh additional consumption by the fan.

4 Efficient compressors

Efficient compressors are a key to low electricity consumption of cold appliances

4.1 More efficient motors

The electric motor is used to run the compressor. Typical design is a two-pole AC induction motor, which runs at ca. 3000 rpm. The motor's stators have two slots for the winding, a principal one which is always active when running the motor and a second which is 90° off phase with the other and steered in three design options. The EU's Eco-design preparatory study for Lot 13 (domestic refrigerators and freezers) describes the following possible improvements (European Commission 2008, p. 467).

BAT

Variable motor speeds

The efficiency of compressors increases with swept volumes through comparatively less mechanical losses. Therefore, when using single-speed motors at the usual ~3000 rpm for smaller appliances, reducing capacity can be achieved only with smaller swept volumes and consequent efficiency losses. One solution is a rated speed motor, which avoids the efficiency losses by using large swept volumes, but at a defined lower speed.

Two-speed motors basically provide the same advantages as a rated-speed motor/compressor, but allow the use of the same motor for higher cooling loads in a second circuit in the same appliance.

Variable speed motors can provide exactly the needed cooling capacity at any time by operating the demanded frequency. Different types are available: Variable speed induction motors (VSIM) and permanent magnet brushless DC motors (BLDC). The latter, which are also known as EC motors, are only used in mobile niche applications (see also next paragraph). The US DOE states possible compressor energy savings of 15-25% and additional noise and vibration reductions (US DOE 2010, p. 3-55).

By 2010, several manufacturers had produced variable speed compressor solutions and their market share is expected to rise even further (Danfoss 2008). This technology is already available, but would roughly double the price of the compressor and is therefore not used very extensively. Still, investment pays back within 7-13 years (depending on the model and other design choices) and could subsequently be economically incorporated into new appliances.

BAT/BNAT

EC Motor

It can be expected that the application of electronically commutated (EC) motors in compressors would lead to electricity savings of about 30 %. However, such kinds of compressors are only currently used in camping and mobile cold appliances, where electricity from a main socket is not always available and is therefore limited to the vehicle battery.

Currently, compressors with an EC motor are much more expensive by a factor of 3 to 4 due to the small production number and the increased production complexity.

4.2 Other compressor improvements

BAT

Compressor design

Further compressor improvements can be achieved by a different suction design, optimising the refrigerant flow around the suction port (direct suction). Other possibilities involve minimising clearance volumes and pressure losses through mufflers, valve ports and reeds (European Commission 2008, p. 469).

The EU Eco-design preparatory study for Lot 13 (domestic refrigerators and freezers) judges reciprocating compressors (using pistons moved by crankshafts and rods) as superior to rotary compressors (like vane pumps), due to the lower efficiency of the best rotary compressors used by some Japanese manufacturers. Furthermore, reciprocating compressors are considered to have higher efficiency improvement potential (European Commission 2008, p. 469).

5 Optimised electronic control

Optimised electronic control is important for the energy-efficient operation of cold appliances

BAT

Better temperature control

The standard temperature measurement is effected through a mechanical thermostat, which is low-cost but not very precise. Consequently, the temperatures in the appliance are very volatile which leads to poorer food preservation and thermodynamic inefficiencies (European Commission 2008, p. 470). Higher-cost electronic thermostats can minimise temperature difference, which leads to higher refrigerant evaporating temperatures and thus saves energy. Other control devices include environment room temperature in the control logic as well.

Better air/temperature distribution

Temperatures may vary highly within the appliance (e.g. due to different loads). Directing cooling exactly towards the parts where it is needed may thus increase efficiency as well. Fans inside the unit and/or mufflers and ducting systems may do this too.

Control of variable speed compressors

Providing exactly the needed amount of cooling can be done by the new generation of compressors with variable speed. They need, however, intelligent electronic control systems. In the best case, they independently control air distribution, compressor operation and defrosting.

Intelligent adaptive defrosting

The evaporator, as the first part in the cooling cycle, where heat is absorbed (cooling provided), needs defrosting from time to time. The standard design is to defrost after a defined amount of compressor cycles. However, in terms of efficiency it is sufficient to defrost only on demand. There are adaptive-defrost systems which calculate defrost need from a more complex function (including number of door openings, compressor operation time and room temperature), and others which use fuzzy logic to train the control system.

6 Other measures

These other measures should also be regarded for energy-efficient operation of cold appliances.

A very promising future cooling technology, which could reduce electricity consumption by 30 – 40 %, is based on the magnetic caloric effect.

BAT

Lower-wattage fans inside the unit

The EU Eco-design preparatory study for the regulation of refrigerators found that by the year 2000, commonly used fans in refrigerators had a power rating of 6-10W AC. Also available on the market, were 4W AC fans paying back within about 7 years. Additionally, there do exist 1W DC fans, which are common in Japanese and some European appliances (European Commission 2008, p. 464).

Soft design options

Some soft design options were identified as leading to significant energy savings under real usage conditions ‘in principle’, but the savings could therefore not be detected, proven and quantified under the existing test conditions. These include:

- More transparent temperature controls, such as accurate temperature display, that could limit the number of instances where consumers mismanage the appliance.

- Intelligent adaptive controls that sense the internal and external temperature conditions and only activate thermal-compensation heaters when needed.

BNAT

Solid State Energy Efficient Cooling / Magnetic refrigeration

The figure overleaf presents the functional principle of magnetic refrigeration.

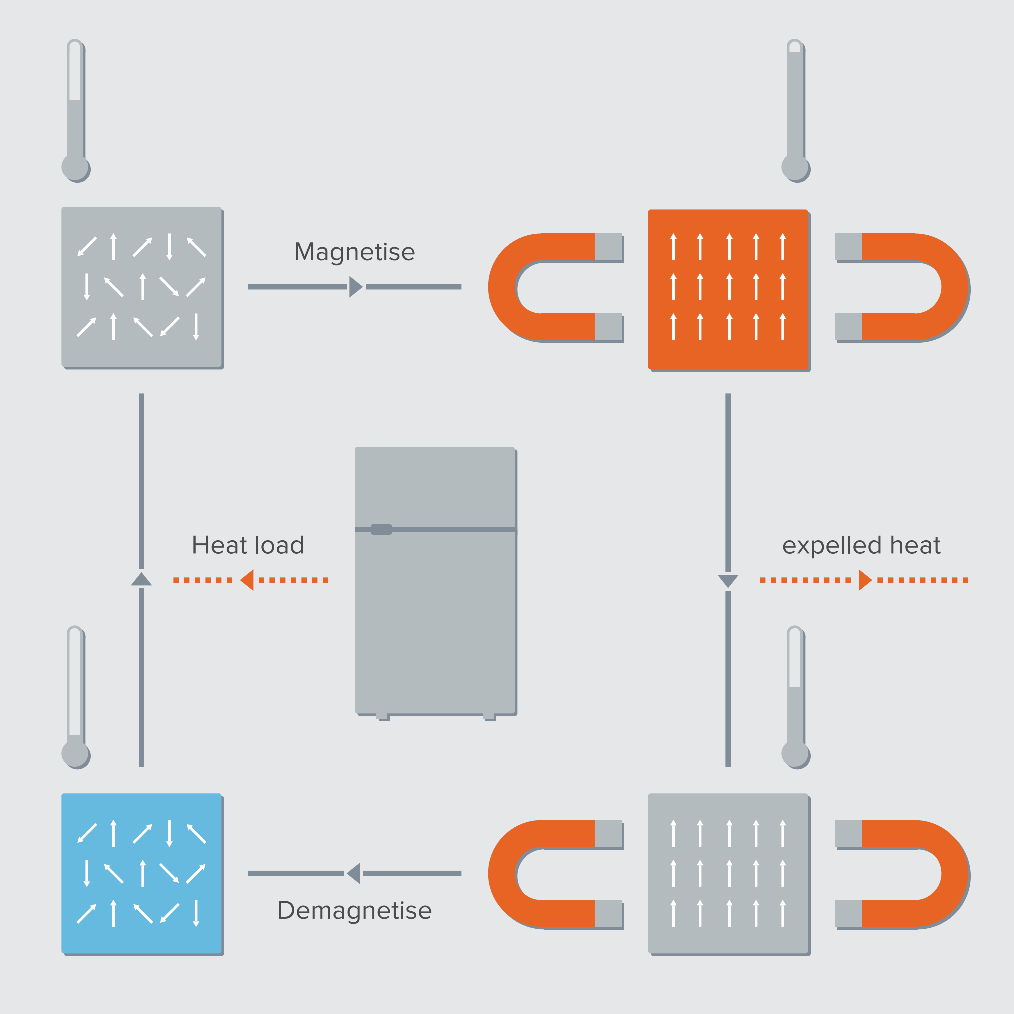


Figure 1 Functional scheme of magnetic cooling (Source: Sandeman 2011)

A conventional refrigerator uses the energetic difference between gas and liquid aggregate state to provide cooling via the expansion and contraction of volatile refrigerants. In an analogous way, the energetic differences between magnetic states in suitable solid refrigerants by reversible magnetization and demagnetization can be harnessed. The resulting "magnetocaloric effect" (MCE) manifests itself by a change in temperature of magnetic material on adiabatic (de)magnetization. In most cases, magnetization is accompanied by a temperature increase, largest around magnetic phase transitions accompanied by a sharp change in the magnetic state of the material (sseec.eu 2011). These characteristics can be found particularly in materials (e.g. rare earth metals like Gadolinium) that undergo a magnetic ordering phase transition (e.g. paramagnetic to ferromagnetic on cooling), in which the magnetization changes sharply over a restricted temperature range, providing a large entropy change (enermat.eu 2011).

Magnetic refrigeration based on the magnetocaloric effect is a promising future cooling technology. The technology itself is considered as environmentally safe, compact, reliable and efficient (enermat.eu 2011). Magnetocaloric cooling technology, initially developed for very low temperature applications like Adiabatic Demagnetization Refrigeration, is currently attracting much interest as an alternative to conventional systems for near-room-temperature refrigeration. Its thermal efficiency is much better than current expansion-compression refrigerators, which drastically reduces the operating costs. The consumption of **electric energy could be reduced by 30 - 40 % compared to recent BAT**. Another strong point is the impact a magnetic refrigerator would bring to current ecological and energy concerns (enermat.eu 2011, C-MAC 2010).

This can be achieved by the abandonment of environmentally hazardous refrigerants (toxic, explosive, greenhouse gases) and lessen the strain household or industrial cooling appliances put on the environment (enermat.eu 2011). Instead, magnetic materials giving rise to high MCE can be conveniently used as solid refrigerants in cooling systems. The span temperature ranges from cryogenic range (detector cooling, liquefaction) up to near-room-temperature applications, according to the magnetic phase transition temperature of the material, which can be conveniently tuned by composition. Therefore, permanent magnet systems (magnetic fields up to about 1 Tesla) are the common choice for small-scale systems, with cooling powers up to a few hundred Watts (enermat.eu 2011). In contrast to traditional domestic cooling appliances with a vapour compression cooling cycle, a magnetic fridge can be optimised according to the specific power requirements of the appliance (Sandeman 2011).

The research for cost-effective applications currently encompasses three main aspects:

- Materials and the optimization of performance parameters of metallic alloys and oxides, magnetocaloric process modelling, temperature ranges, synthesis and processing costs and durability,
- Devices and their thermal cycles, overall efficiency, magnets and materials configurations, thermal exchange fluids
- Design adaptation for specific applications like electronic components, home or industrial equipment (enermat.eu 2011).

The first working prototype of a refrigerator based on the magnetocaloric effect was intended to be available in 2012 (camfridge.com 2011).

7 Design options to reduce the environmental impact of refrigerants and foaming agents

Refrigerants with high global warming potential (GWP) can easily be replaced by natural refrigerants such as hydrocarbons or carbon dioxide

The switch from conventional refrigerants and foaming agents, such as hydro-fluoro-carbons (HFCs), to more sustainable alternatives is possible without technical problems. It will not affect energy efficiency and costs.

In Europe, therefore, the use of natural gases (Propane, Butane...) and CO_2 (especially in the commercial sector) as refrigerant and Pentane as foaming agent is already widely applied. Many countries in the world have the same opportunity to reduce greenhouse gas emissions by implementing this switch.

Refrigerant	**Label**	**Applicable**	**Applied**	**Global Warming Potential (GWP)**	**Ozone Depletion Potential (ODP)**
HFC (popular standard)[1]	e.g. R134a			1,400 (100 years)	High
Carbon dioxide (CO_2)	R744	General	Europe, Japan (commercial)	1	0
Ammonia		Large (commercial) freezers	General (commercial)	0	0
Hydrocarbons	e.g. R600a, R290	General	Refrigerators and Freezers (Europe) Air-conditioning (world)	<3	0

Table 3: Refrigerants and their Global Warming and Ozone Depletion Potentials
Source: beyondhfcs.org

7.1 Refrigerants in use worldwide

As a refrigerant, several agents are or have been used worldwide.

In former times, chloro-fluoro-carbons (CFC) were mainly used, but due to their OZON-depletion character, production of CFC is forbidden since 2000 (Montreal Protocol).

The then used alternative, hydro-chloro-fluoro-carbons (HCFC), has a smaller Ozone depletion potential than CFC but a high greenhouse gas potential. HCFCs are not used anymore in household cooling appliances in Europe, but are still in use in the commercial sector and in many countries outside Europe. Phase out is planned for 2020 (appendix to the Montreal Protocol).

The current conventional alternative to CFCs and HCFCs, hydro-fluoro-carbons (HFC), has no Ozone depletion potential but a high greenhouse gas potential of 1400. In Europe, it has also been replaced by natural gases to almost 100 % in household cooling appliances, but it is still in use in household appliances outside Europe and as well in the commercial sector - including Europe.

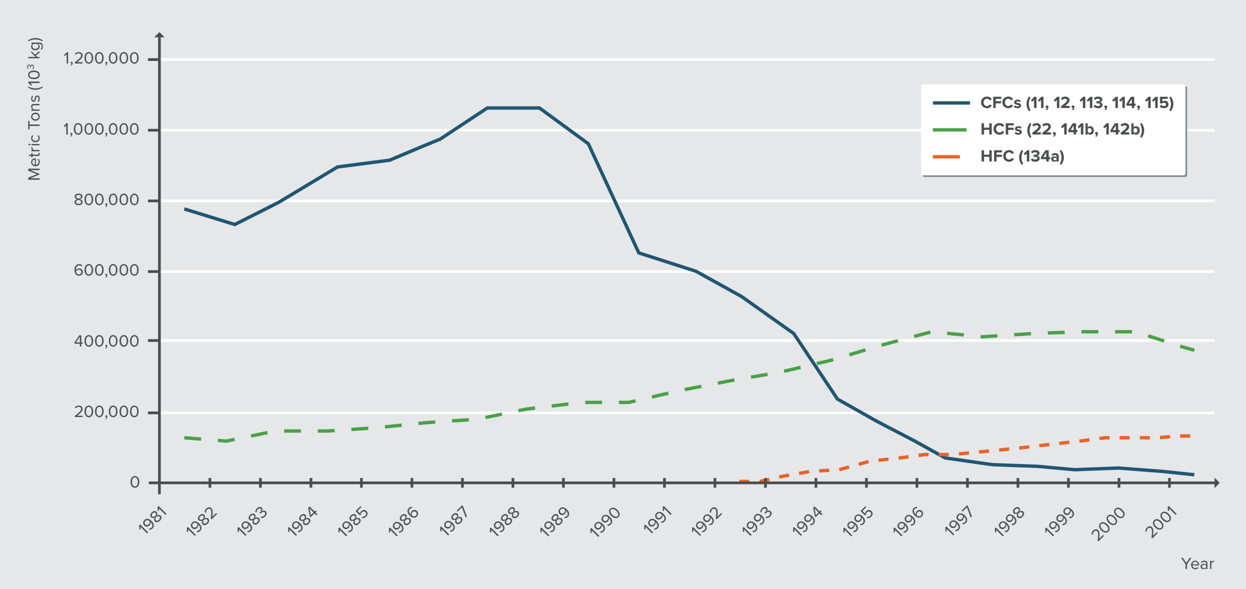


Figure 2: Worldwide Production of CFCs, HCFCs and HFCs

Source: UNEP: http://www.beyondhfcs.org/files/studies/UNEP-Backgrounder-Ozone-Portection.pdf

In 2007, approximately 350,000 tonnes of HFCs (Federal Environment Agency 2010, p.10) were produced. This represents a severe GWP.

Fluorocarbons: Usage and problems

In 2010, fluorinated gases (F-gases) represented approximately 1-2% of all climate-damaging gases, which roughly equals the same share as global air traffic. In a “business-as-usual”-scenario, this is expected to increase to about 5,9% by 2050 (Federal Environment Agency 2010, p. 13).

Chlorofluorocarbons (CFCs) are banned and being phased out (see Figure 2). But several other F-gases are still (and in some regions increasingly) used:

- Hydro chlorofluorocarbons (HCFCs)
- Hydro fluorocarbons (HFCs)
- Per fluorocarbons (PFCs)

- Sulphur hexafluoride (SF_6)

These gases have (apart from their ozone depletion potential, ODP) very high Global Warming Potential (GWP) which is in the thousands, meaning they contribute to Global Warming more than 1000 times as much as the same amount of carbon dioxide (CO_2). Additionally, they are climate-disruptive - especially in the short term. This will make them very attractive as an effective climate change mitigation potential, if phased out immediately.

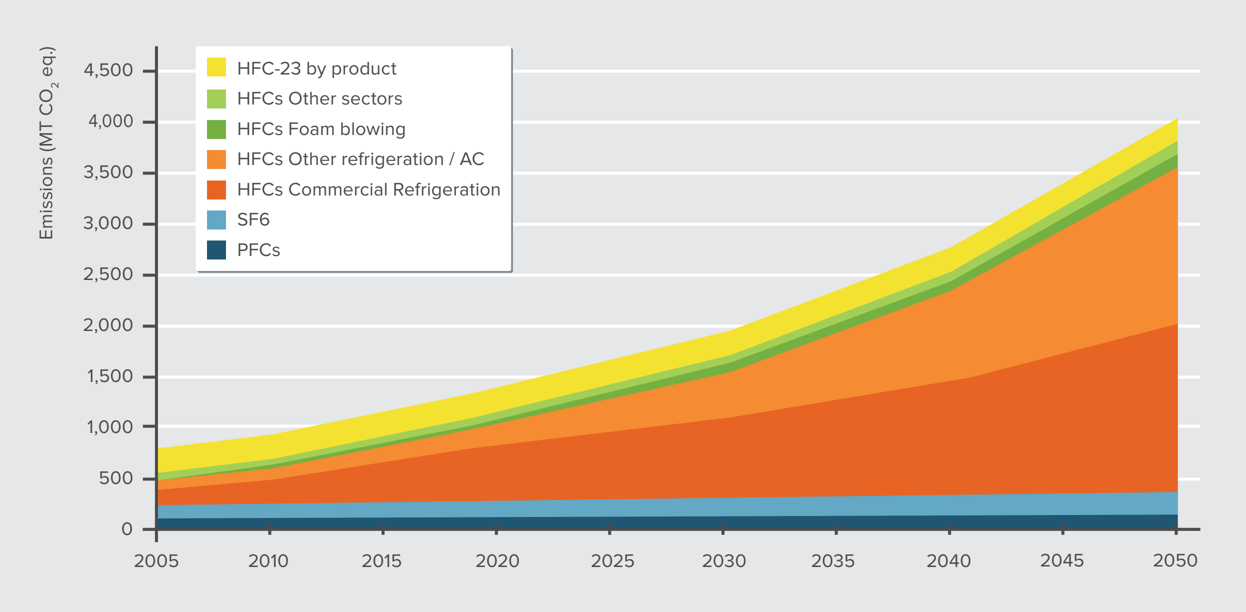


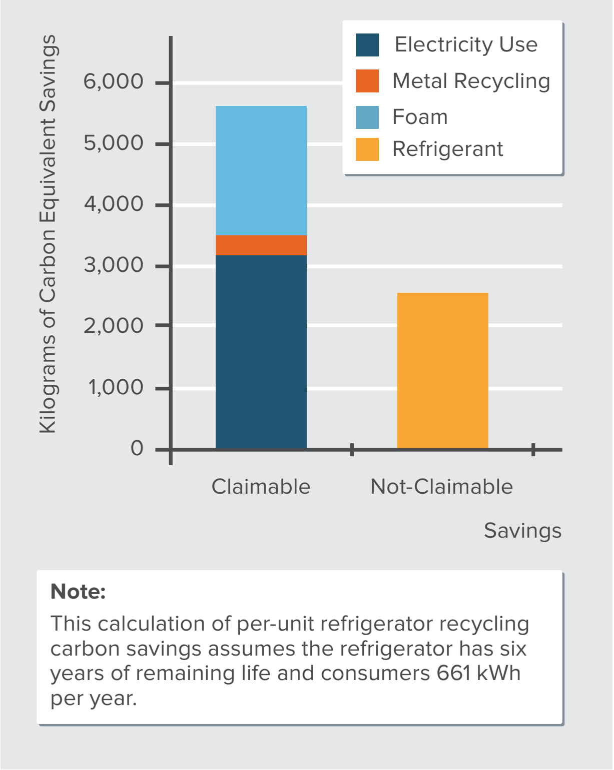
Figure 3 Forecast of emissions of fluorinated gases in a business-as-usual scenario, with HFCs split by use (Source: Federal Environment Agency 2010, p. 14)

7.2 Foaming agents

In some regions of the world, e.g. Europe and North America, refrigerants, most often CFCs and HCFCs, are recovered before dismantling or disposing of a refrigerator.

In contrast the CFCs or HCFCs that are used as blowing agents and are trapped in the foam are not recycled. As can be seen in Figure 4, the share of global warming potential of the refrigerant and of the foaming agent are in the same order and should not be neglected. So full recoveries of the foam will nearly double the expected reduction in claimable global warming potential over simple recovery of the refrigerant (Source: U.S. Environmental Protection Agency 2007).

Therefore, to reduce the global warming potential of refrigerators as much as possible, a refrigerator should be fully recycled.



Note:
This calculation of per-unit refrigerator recycling carbon savings assumes the refrigerator has six years of remaining life and consumers 661 kWh per year.

Figure 4: Carbon savings per unit from refrigerator recycling (Source: D&R International, April 2008)

7.3 Alternative refrigerants and foaming agents

Hydrocarbons (butane, propane)

Natural gas technology is often even more efficient and less costly than FC technology and available for nearly every cooling application. However, this renders HFCs unnecessary and hence, a whole market. If market actors are strong, this may be one explication, as to why in some regions, alternative technologies are still rarely found (Maté, Davies, Kanter 2009, p.53).

Carbon dioxide (CO_2)

CO_2 may be used as refrigerant as well, with an ODP of 0 and a GWP of 1, but as it is used in a closed cycle and limited quantities, this means practically negligible emissions.

Ammonia

Although NH_3 is produced synthetically as a refrigerant, it is regarded as “natural” because it occurs naturally as well. It has an ODP and GWP of 0. Until now, it has been mainly used in large-scale commercial appliances. One reason for this is that it requires to be maintained in closed circuits, due to its potential respiratory irritation.

8 References

ADEME (2000):
Diagnostic énergétique des installations frigorifiques industrielles.

Beyondhfcs.org (2009):
http://www.beyondhfcs.org/files/studies/2009-state-of-the-world-into-a-warming-world.pdf

C-MAC (2010):
Magnetocaloric Materials for Refriegeration. http://cma-ecnoe.net/cma/cma_homepage.nsf/vwRes/C-MAC_02/$FILE/C-MAC_Flyer_Magnetocalorics.pdf
camfridge.com (2011): Pan-European network Website, Cambridge, http://www.camfridge.com, Accessed: 06/2011

D&R International (2008):
Information based on “Responsible Appliance Disposal Program 2007 Annual Report,” U.S. Environmental Protection Agency; “Evaluation Study of the 2004-2005 Statewide Residential Appliance Recycling Program,” California Public Utilities Commission, April 2008.

Danfoss (2008):
ApexxTM VSH series variable speed scroll compressors for commercial air conditioning. http://www.danfoss.com/NR/rdonlyres/ED489694-517C-4A3D-BE71-0586F73B20A3/0/Apexx_Brochure.pdf

enermat.eu (2011):
Magnetocalorics, Text by Amaral, V., Universidade de Aveiro, Portugal, http://www.enermat.eu/site/index.php?page=technology&item=10, Accessed: 06/2011

European Commission (2008):
Lot 13: Domestic Refridgerators & Freezers. Final Report.

Federal Environment Agency (Umweltbundesamt) (2010):
Fluorierte Treibhausgase vermeiden. Wege zum Ausstieg.

LBNL - Lawrence Berkeley National Laboratory (2006):
Gas Filled Panels. High Performance Insulation. http://gfp.lbl.gov/.

Maté, Janos; Davies, Kert; Kanter, David (2009):
The Risks of Other Greenhouse Gases. In: The Worldwatch Institute (ed.). State of the World. Into a Warming World.

Muller, Christian; Vasile, Carmen; Risser, Michel; Heitzler, Jean-Claude; Keith, Bernard (2010):

New Air-Conditioning and Refrigeration Magnetocaloric Gas Free System. International Symposium on Next-generation Air Conditioning and Refrigeration Technology, 17 – 19 February 2010, Tokyo. Responsible Appliance Disposal Program 2007 Annual Report," U.S. Environmental Protection Agency

Sandeman, K. (2011):
Gas-free refrigeration, Magnetics Technology International, 01/2011, ISSN 2047-0509, http://viewer.zmags.com/publication/9c6782fc#/9c6782fc/32

Sandeman, K.; Caplin, A.; Moore, J.; Morrison, K.; Gercsi, Z.; Cohen, L. (2009):
Magnetic Materials for Energy Efficient Refrigeration.

sseec.eu (2011):
SSEEC (Solid State Energy Efficient Cooling) Project Website, http://www.sseec.eu/, Accessed: 06/2011

beyondhfcs.org (NA):
Technical handbook: Guidelines for the safe use of hydrocarbon refrigerants. A handbook for engineers, technicians, trainers and policy-makers - For a climate-friendly cooling. http://www.beyondhfcs.org/files/studies/gtz-hydrocarbon-refrigerants-guidelines-safety.pdf

U.S. Environmental Protection Agency (2007):
Responsible Appliance Disposal Program. Annual Report 2007.

UNEP (2003):
BACKGROUNDER Basic Facts and Data on the Science and Politics of Ozone Protection. http://www.beyondhfcs.org/files/studies/UNEP-Backgrounder-Ozone-Portection.pdf

US DOE (2010):
Technical Support Document - EERE - U.S. Department of Energy. http://www1.eere.energy.gov/buildings/appliance_standards/residential/pdfs/refrig_nopr_tsd_2010-09-23.pdf

US DOE (2011):
Berkeley Lab's Gas-filled Insulation Rivals Fiber in Buildings Sector. http://energy.gov/articles/berkeley-labs-gas-filled-insulation-rivals-fiber-buildings-sector

bigEE

Your guide to energy efficiency in buildings.

bigee.net

bigEE is an international initiative of research institutes for technical and policy advice and public agencies in the field of energy and climate, co-ordinated by the Wuppertal Institute (Germany). Its aim is to develop the international web-based knowledge platform bigee.net for energy efficiency in buildings, building-related technologies, and appliances in the world's main climatic zones.

The bigee.net platform informs users about energy efficiency options and savings potentials, net benefits and how policy can support achieving those savings. Targeted information is paired with recommendations and examples of good practice.

Co-ordinated by

Wuppertal Institute
for Climate, Environment
and Energy

Partners to date

sonedi

cscp

Financial support

Federal Ministry for the
Environment, Nature Conservat
and Nuclear Safety

Dr. Stefan Thomas • bigee@**wupperinst.org**
Wuppertal Institute for Climate, Environment and Energy • Doeppersberg 19 • 42103 Wuppertal • Germany • Phone: +49 (0)202 2492-129