



Natural Refrigerants for Climate-Friendly Cooling Technologies



climate



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Imprint

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Foreword

Dear readers!

As the standard of living has risen in many countries, the demand for refrigerants for cooling and air-conditioning has been steadily increasing. According to estimations by the German Federal Environment Agency, the emissions from fluorinated gases, so called F-gases, are expected to increase threefold by 2050 and will comprise more than six per cent of total greenhouse gas emissions globally. These trends would negate the positive steps that have been achieved throughout the years in other areas of climate protection.

In response to these trends of growing emissions from fluorinated gases the European Union has taken measures towards the reduction of F-gases. From 2015 to 2030 the production of F-gases shall be phased down to one fifth of the amounts produced in 2015. For this goal to be achieved, we must transition to climate-friendly natural refrigerants such as carbon dioxide, ammonia and hydrocarbons within the next few years. The knowledge about alternative solutions is well-established in technologically developed countries. The transition to natural refrigerants would additionally improve the potential for energy efficiency. On behalf of the Bavarian Ministry of the Environment and Consumer Protection, the Bavarian Environment Agency will highlight solutions in this brochure by which F-gases could gradually be replaced and in parallel, the energy saving potential increased.

The goal for reduction of F-gases worldwide cannot be achieved if the transition to climate-friendly natural refrigerants is pursued by Bavaria or Europe alone. Global efforts are needed in this respect. The international community can only deal with this challenge if they work closely with one another. The key to success lies in international cooperation, the exchange of technological expertise and experiences. We are delighted to have Israel as a partner in this challenge. Israel is ready for the necessary technological break-through and is dependent on sustainable solutions for the refrigeration and air-conditioning sector for the future. Together with our partner, the Deutsche Gesellschaft für internationale Zusammenarbeit GmbH (GIZ, German International Cooperation) with its excellent experience acquired in this field, we would like to promote sustainable, climate-friendly refrigeration and air conditioning.

A handwritten signature in blue ink, appearing to be 'Ulrike Scharf', written in a cursive style.

Ulrike Scharf MdL
Bavarian State Minister for
Environment and Consumer Protection

Foreword

Dear readers!

Modern refrigeration and air-conditioning systems already contain various climate-friendly, natural refrigerants that are less harmful to the environment than climate-damaging fluorinated refrigerants. In addition, they are often more energy efficient. However, fluorinated refrigerants that contribute heavily to global warming still dominate the market. The Bavarian Environment Agency is committed to promoting the reduction of climate-damaging fluorinated gases in air-conditioning and refrigeration systems in Bavaria. Operators and decision-makers should be encouraged to transition to climate-friendly natural refrigerants and should be offered incentives to switch to new and innovative refrigeration technologies.

Transitioning to alternative technologies is an effective method to reduce greenhouse gas emissions while simultaneously increasing energy and resource efficiency. Current activities in this direction include the cooperation with Israel for the reduction of emissions from fluorinated refrigerants in the commercial refrigeration sector. Owing to the climatic conditions, Israel records a higher consumption of air-conditioning and refrigeration equipment than Germany. Therefore, transitioning to more climate-friendly refrigerants is also supported by Israel. Technology transfer implies a benefit for Bavaria and Israel: Bavarian and Israeli companies developing and successfully implementing alternative refrigeration and air-conditioning technologies will strengthen their international technology leadership in this sector.

This brochure summarises some case studies from Bavaria. It demonstrates that a transition to natural refrigerants is viable, from environmental, energy and economical perspectives.



Claus Kumutat
President of the Bavarian Environment Agency



Refrigeration Technology – A Contribution to Higher Living Standards



Refrigeration is a key technology, which enjoys a wide application, be it in the food processing industry, for the air-conditioning of buildings or in the manufacture of medicines. It contributes significantly to the rising standard of living and enables a healthy and comfortable life.

Climate-Damaging Gases in Refrigerants

Refrigeration has been gaining importance worldwide. However, refrigeration and air-conditioning systems often contain chemicals that contribute to global warming. These harmful chemicals include so-called F-gases (fluorinated gases) which form an integral part of the refrigerant. F-gases are partially (HFCs) or totally fluorinated hydrocarbons (PFCs), which are used in various chemical blends as refrigerants. The equipment and products that contain F-gases include, for example, industrial cooling and refrigeration equipment, freezers, air conditioners in buildings and cars, heat pumps, refrigeration in trucks, electrical switchgear, medical aerosols, certain insulation and foams as well as firefighting equipment.

HFCs and PFCs are substitutes for fluorinated and chlorinated hydrocarbons (chloro-fluorocarbons (CFCs) and partially halogenated chlorofluorocarbons (HCFCs)). The first generation of chemical refrigerants had particular advantages: They were odorless, non-corrosive, non-flammable, non-toxic and thus considered safer to use. However, during the 1970s and 1980s it was proven that CFC-containing substances were responsible for the depletion of the stratospheric ozone layer. Since then, the production and use of ozone-depleting substances has been strictly regulated internationally through the Montreal Protocol signed in 1987. While the substitutes for CFCs and HCFCs (the HFCs and PFCs) do not harm the ozone, they contribute significantly to the greenhouse effect, as some of these substances have very high global warming potentials. Owing to increased efforts for climate protection, the use of such F-gases has been regulated internationally since 1997 by the Kyoto Protocol.



Refrigerators and air conditioners can contain climate-damaging fluorinated gases.

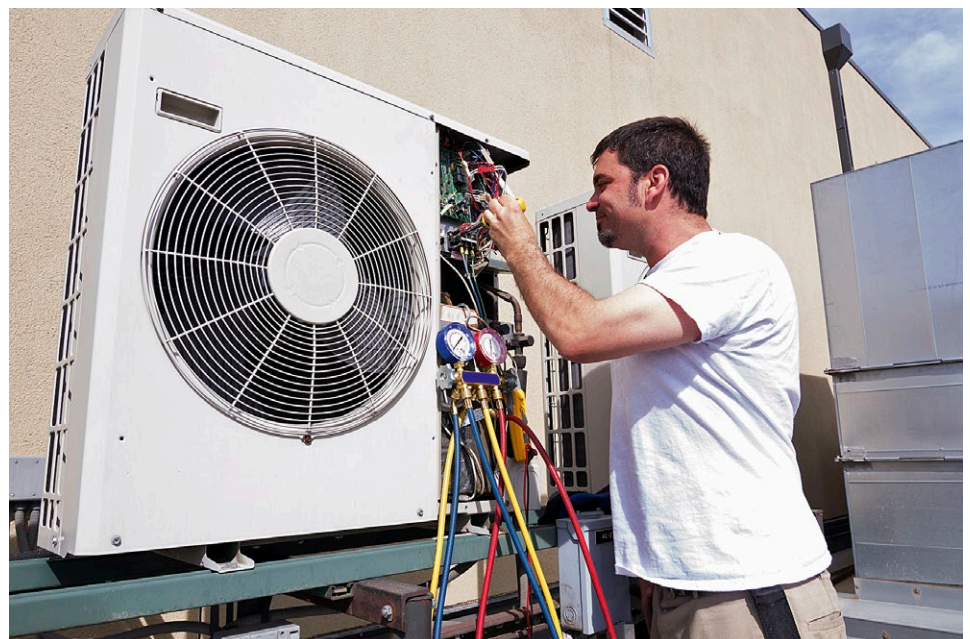
Many sectors rely on refrigeration, for example, passenger and freight transport, food production and industry.



When refrigerants containing F-gases escape into the atmosphere during maintenance or through leakages while the equipment is in operation, they contribute to the greenhouse effect by reabsorbing the heat radiated by the Earth's surface into the atmosphere. In addition, halogenated fluorocarbons are hardly degradable in the atmosphere and have an atmospheric lifetime of up to 100 years or more. The potential of a substance to contribute to the greenhouse gas effect is expressed as Global Warming Potential (GWP) or as CO₂ equivalent, whereby the respective global warming potential of a particular substance is compared to that of CO₂. For example, the HFC refrigerant R-404A has a GWP of 3,922 as compared to CO₂ which has a global warming potential of 1. This means that the release of one kilogram of refrigerant R-404A contributes 3,922 times more to the greenhouse effect within the first 100 years, as compared to the release of one kilogram of CO₂.

The Bavarian State Ministry of the Environment and Consumer Protection and the Bavarian Environment Agency support the transition to natural and climate-friendly refrigerants. Together, they are committed to the reduction of climate-damaging F-gases in refrigeration and air-conditioning equipment and see a great opportunity for the development of refrigeration technologies based on natural refrigerants.

Servicing and maintenance of air-conditioning and refrigeration equipment must be carried out by certified personnel.





Project for the Reduction of Climate-Damaging F-gases in Bavaria



The reduction of climate-damaging chemicals in refrigeration and air-conditioning is an important contribution to international climate protection. A large number of operators and decision-makers in Bavaria are affected by this issue. Only through international cooperation can climate protection be taken forward on the right path. The Bavarian Environment Agency cooperates with the Israel Ministry of Environmental Protection and the GIZ Proklima to promote the transition to natural refrigerants in Israel.

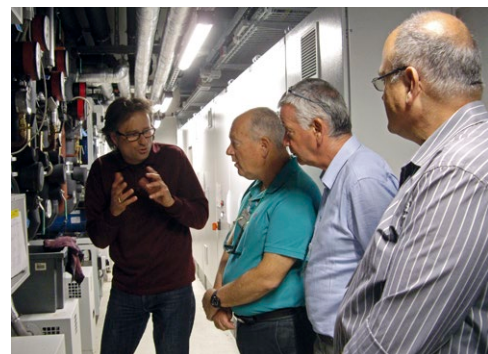
Supporting Bavarian Businesses in the Transition

Climate change is high on the priority list of environmental issues in Bavaria. This is one of the reasons why the Bavarian State Ministry of the Environment and Consumer Protection initiated the project 'reduction of climate-damaging F-gases in refrigeration and air-conditioning equipment in Bavaria' at the Bavarian Environment Agency. Bavarian firms, especially small and medium scale enterprises, will be supported by the Bavarian Environment Agency in the transition to natural refrigerants. To this effect, the Bavarian Environment Agency shall provide information and lead workshops and discussions for refrigeration and air-conditioning associations and operators of refrigeration equipment.

Cooperation between Bavaria and Israel

Within the framework of the project, collaboration with the Israel Ministry of Environmental Protection has been initiated. The main aim is to convince operators of refrigeration systems in Israel to transition to natural refrigerants. The lead partner in this project is the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ, German International Cooperation). The cooperation with Israel is focussed on commercial refrigeration and on training programs on the use of natural refrigerants. Training on safety aspects is an integral part of the project; Israeli lecturers for refrigeration and air-conditioning shall be trained at the Federal Technical College for Refrigeration and Air-Conditioning Equipment in Frankfurt so that they can, in turn, act as multipliers and conduct training sessions for refrigeration technicians in Israel. In Bavaria, the participants shall visit various companies that use natural refrigerants and can experience, first-hand, the operation of the technology. Furthermore, technical workshops for refrigeration, heating and air-conditioning (RAC) associations and decision-makers in Israel shall be held to impart knowledge about issues such as energy efficiency, risk mitigation and training of technicians.

Trainers for air-conditioning and refrigeration technology from Israel will be trained on the operation of systems with natural refrigerants.



Israeli experts on refrigeration and air-conditioning visit a Bavarian company that operates technologies based on natural refrigerants.

'Do it yourself' is one of the aspects of the training concept of the 'Cool Training' organised by the GIZ Proklima. At the College of Refrigeration and Air-Conditioning in Frankfurt, participants work with copper wiring in the laboratory and complete a brazing test.



EU Decision to Phase-Down F-gases



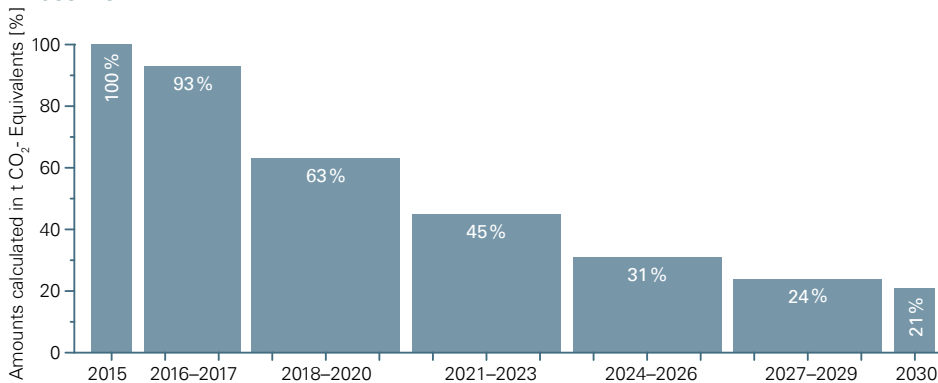
The EU regulates the production and use of F-gases. Products and equipment filled with refrigerants having a high Global Warming Potential (GWP) must, in future, meet more stringent requirements. In addition to the reduction of emissions caused by F-gases, the objective of the EU F-Gas-Directive is to enable a transition to alternative natural refrigerants which cause less harm to the climate than the F-gases used today.

Step by Step: Reducing the Production and Use of F-gases in Europe

The demand for refrigeration and air-conditioning worldwide has been increasing. In countries with very high ambient temperatures the demand for air-conditioning increases, especially in the summer months. Refrigerators & freezers are typical electrical appliances that are present in almost every household. According to projections, the demand for refrigerators and air conditioners is expected to rise in the future, especially in emerging economies such as China, India and Brazil. Even in Europe, a steady increase in the demand for refrigeration is expected owing to rising prosperity. However, this wider use of refrigeration applications will increase the emissions of harmful greenhouse gases into the atmosphere.



Phase-Down



The amounts of HFCs placed on the market in the EU will be reduced step by step.

The binding emission targets set by the Kyoto Protocol for developed countries would be jeopardized by the expected increase in climate-damaging greenhouse gas emissions from refrigeration and air conditioning. The European Union has responded to the projected increase in HFC consumption with regulations. The Regulation (EC) No. 1005/2009 regulates substances that deplete the ozone layer while Regulation (EU) No. 517/2014 regulates the production and use of F-gas-containing substances. The implementation of these guidelines into national law is supplemented by two regulations in Germany: the Chemicals-Ozone Protection Regulation and the Chemicals-Climate Protection Regulation.

By 2030, the total quantity of HFCs in the EU will be reduced to one fifth of the amounts estimated in 2014. In order to reach this goal, a 'Phase-Down' procedure prescribes gradually reducing the emissions of HFCs.

According to the EU regulations, F-gas-containing substances are subjected to a so-called 'Phase-down', i.e. their share on the market will be gradually reduced. HCFCs and HFCs shall only be available in small quantities by 2020 and 2030 respectively, and their use shall be limited to certain applications.

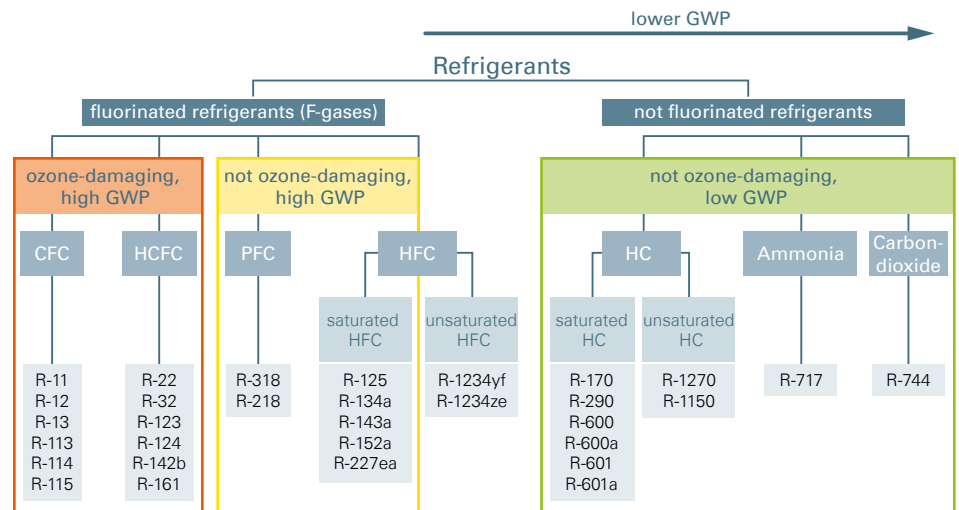
By 2030, the HFC quantity available on the market will be reduced to 21% of the quantity from 2015. Just as in the case of HCFCs, which have been regulated in the EU since 2009, HFCs and PFCs (regulated in the EU since 2014) are expected to experience an artificial shortage in the coming years. This could encourage the market for natural refrigerants to broaden.



A correctly labelled cylinder filled with the refrigerant Propane (R-290).

Natural Refrigerants Replace F-gases

The natural alternative refrigerants to replace F-gases include carbon dioxide, ammonia, water and saturated hydrocarbons (HC) such as propane or butane. These refrigerants, coupled with the right technology, are also suitable for countries with high ambient temperatures and are generally associated with higher energy efficiency and lower emissions. In addition, through the energy efficient design of new cooling systems, special features, such as heat recovery and production of pressured air, have now become standard features. Natural refrigerants can be used for different applications and cooling capacities, whether for air-conditioners, freezers, commercial refrigeration, heat pumps or for foam blowing various insulation materials. The Bavarian Environment Agency is focused on commercial refrigeration in the food retail sector.



Natural refrigerants have a low global warming potential (GWP) as compared to F-gases and thus lower climate-damaging effects. (adapted from Dr. Daniel Colbourne, Re-phridge)



Category	HCFCs and HFCs	Natural Refrigerants
Refrigeration Capacity	Fluctuations in cooling capacity possible	Thermodynamic properties are often comparatively better than those of HCFCs and HFCs
Maintenance and Leak tests	Regular leak checks mandatory (EU-Directives)	Leak checks not mandatory by Directives
Leakage Rates and Emissions	<ul style="list-style-type: none"> ■ Could be higher, especially from older systems ■ Emissions through leakages are climate-damaging 	<ul style="list-style-type: none"> ■ Significantly lower ■ Emissions through leakages are not or less climate-damaging
Economical Aspects	Capital and operational costs are high	<ul style="list-style-type: none"> ■ Initial capital costs high ■ Return on investment is short when combined with measures such as heat recovery and financial support or funding
Refrigerant Costs	Expected rise in price for refrigerants with high GWP owing to shortage	Price relatively stable
Safety Aspects	In most cases, no extra safety measures need to be taken	<ul style="list-style-type: none"> ■ Hydrocarbons, such as Propane (R-290): Greater risk of explosions, thus explosion prevention measures are necessary ■ Carbon dioxide (R-744) and Ammonia (R-717): Detectors and gas escape alarms necessary
Environmental Aspects	<ul style="list-style-type: none"> ■ Higher GWP, HCFCs ozone depleting ■ Produce persistent wastes ■ Production from limited resources (Fluorspar) ■ Recycling and destruction expensive 	<ul style="list-style-type: none"> ■ Low or no GWP, not ozone depleting ■ Wastes not persistent ■ Production not from limited resources ■ Recycling and destruction easier and cheaper
Energy Efficiency	Energy efficiency depends on type and age of the system	Newer systems are often more energy efficient through measures such as heat recovery and web-based remote monitoring systems



Comparison of natural refrigerants with HCFC and HFC-based refrigerants

Higher Energy Efficiency through Natural Refrigerants



Energy efficiency is one of the key factors in reducing operating costs in refrigeration and air-conditioning systems. Newer facilities, for example, are integrated with a central control cabinet from which all refrigerators, refrigerated counters and deep-freeze areas can be controlled. Thus, malfunctions can be quickly identified and often repaired using remote monitoring software. Speedy solutions to operational problems contribute, among other things, to reduce the energy losses of the cooling system.

Energy Efficiency of Refrigeration Systems: Many Factors Play a Role

Worldwide, refrigeration and air-conditioning generates emissions of around 4.8 Gt (1 Gigaton = 10^9 t) of CO₂ equivalents (CO₂-eq) per year. In a business-as-usual scenario emissions for 2030 are projected at more than 12 Gt CO₂-eq. One third of these emissions arise directly from the equipment, while two-thirds arise as indirect emissions from the energy input for cooling systems. The direct emissions are caused by refrigerant leaks during maintenance or operation of the equipment. Indirect emissions depend on the source of the energy input; that is, the 'dirtier' the source (such as coal), the higher the emissions. If the electrical input is sourced from renewable energies such as wind, photovoltaic or hydroelectric power, the indirect emissions will decrease. The potential to save energy and to reduce emissions from refrigeration and air-conditioning systems are largely dependent on the electricity consumption and the design of the system. Small measures, such as regular leakage inspections and maintenance, can save a lot of energy. Compared to conventional refrigerants, energy efficiency with natural refrigerants can be improved by 50% or more.

The energy efficiency of existing refrigeration and air-conditioning systems can be influenced by a few simple measures, such as regular maintenance and cleaning of the condenser. Some aspects can be considered in advance, when new air-conditioning and refrigeration equipment is bought or a transition to natural refrigerants is made. However, some of these measures are associated with higher investment costs but have a relatively short return-on-investment through lower energy consumption.

Several factors influence the energy efficiency of refrigeration or air-conditioning systems, such as the choice of refrigerant, the ambient temperatures during the summer months and the expected cooling loads. The following measures list some points which could be considered during the planning process in order to improve the energy efficiency of the refrigeration system:

- Correct dimensioning of components
- Selection of wiring and circuitry
- Optimal refrigerant charge
- Choice of insulation material
- Choice of oil
- Choice of compressor
- Use of an expansion valve instead of a capillary tube
- Regular leakage tests and maintenance
- Avoiding pressure losses in the system
- Minimizing losses through components (for example pumps or lighting)



Top and middle: typical central electric control cabinet of a commercial refrigeration system

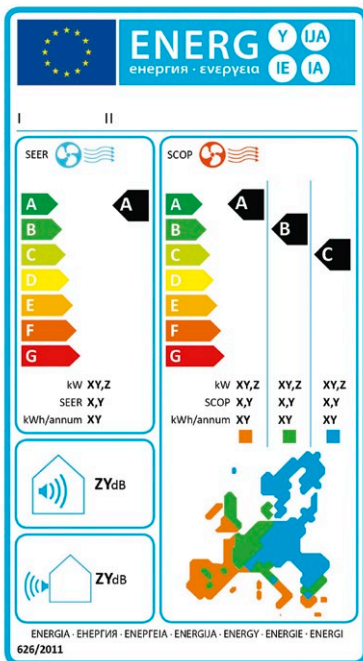
Bottom: high pressure piping of a refrigeration system

Heat Recovery

The cooling process produces waste heat, which is usually transferred to the air or cooling water by the condenser. The recovery of this waste heat for use in other processes is called heat recovery. Heat recovery is an important factor that affects the energy efficiency of a refrigeration system: the more residual heat recovered from the refrigeration cycle, the less heat required from external sources. The heat obtained from heat recovery can be used for example, for heating water or for heating rooms and floors. This saves heating costs and the overall energy efficiency of the system can be increased.

Eco Design and Energy Labelling

Further aspects for manufacturers and consumers of air conditioners and refrigeration systems are product design and energy labelling. The European Ecodesign Directive 2009/125/EC on 'establishing a framework for the setting of eco-design requirements for energy-related products' requires that energy-related products should be designed to limit greenhouse gas emissions, minimise environmental impact and conserve resources for the entire life-cycle of the product. The EU Directive 2010/30/EU on 'labelling and standard product information of the consumption of energy and other resources by energy-related products' and the European Commission Delegated Regulation (EU) No. 626/2011 with 'regard to energy labelling of air-conditioners' govern the energy labelling requirements for air-conditioners in the EU. These require that the electricity consumption of air-conditioners must be measured and clearly stated on the product documentation. This includes, in particular, a mention of the seasonal energy efficiency ratio for the cooling season (SEER) and the seasonal coefficient of performance for the whole designated heating season (SCOP). The electricity consumption and noise level of the appliance must also be labelled on the product. Customers can make an informed choice of such appliances and it is easier to identify appliances with lower energy efficiencies.

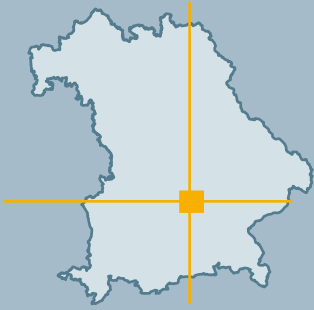


Case Studies from Bavaria



Practical examples from Bavaria demonstrate that refrigeration systems based on natural refrigerants can be acquired and operated in an economical and energy efficient manner. All operators of the nine following examples of commercial refrigeration systems are convinced that natural refrigerants provide sustainable solutions for the future.

Hops Processing Hallertau – ‘Natural refrigeration for 7,000 tons of hops pellets’



Facts about the Facility

Location:	Hallertauer Hopfenveredelungsgesellschaft m.b.H., 84072 Au in der Hallertau
Companies involved:	Fa. Heilmeier, R. Schiessl GmbH
Contact:	Mr Robert Baust, r.baust@schliessl-kaelte.de

Facility – Use, cooling capacity, refrigerant, refrigerant charge

The refrigeration system of the hops processing facility at Hallertau serves the production of hops pellets from raw hops. The cascade system with three reciprocating compressors, all of which are speed controlled, uses propane (R-290) refrigerant for the upper stage and CO₂ (R-744) refrigerant for the lower stage. R-744 is used subcritically. The plant is designed for a brine circuit with cooling temperature of –40 °C and around 130 kW of cooling capacity. The charge of the plant is approximately 44 kg of R-290 and approximately 30 kg of R-744.

Reasons for the transition to natural refrigerants

As the existing refrigeration system had become too small and outdated, a completely new facility had to be planned. The operator preferred an innovative refrigeration facility with environmentally friendly refrigerants with low life-cycle costs.



Condenser with an air cooled heat exchanger on the rooftop of the company

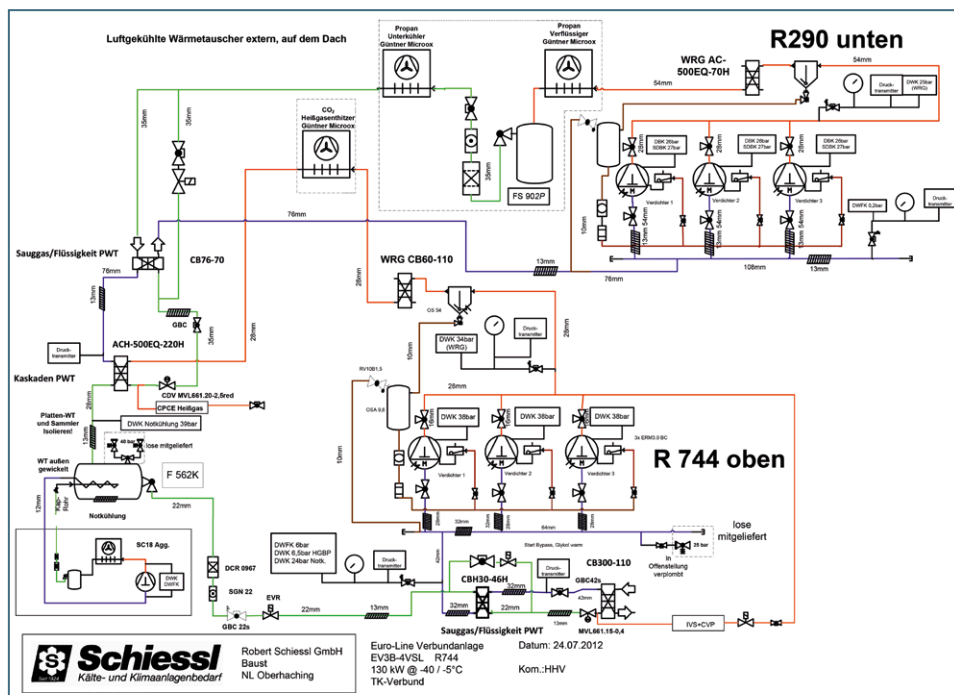
Technical Data of the Facility

Power required:	48,000 kWh per year
COP*	
summer/winter:	For an outside temperature of 0 °C, a COP of 2.4 was calculated with a single manual measurement.
Costs:	Owing to the low operating and maintenance costs (as compared to an R-404A system), the choice for a CO ₂ system was made.
Challenges:	Other than a problem caused by a faulty regulator, no further problems have occurred within the operating period of three years.

*Coefficient of Performance

Special features of the facility

- The system has been designed to consume as little energy as possible. To achieve this, the following measures have been implemented:
 - The lead compressor and the motor of the condenser were each fitted with frequency inverters;
 - The evaporators were equipped with electronic fuel injectors;
 - For both cycles, R-290 and R-744, heat recovery is operated;
 - The use of the facility is optimally sized to meet the requirements of processing the hops between the harvest in autumn till the completion of processing the following May. In the summer months, the facility is tested and serviced and this time is used as a buffer.
- The facility has a generously sized heat exchanger to optimise the refrigeration circuit. In addition, there is a central control panel to regulate and monitor the entire system.
- The facility also has air cooled sub-coolers for R-290 and desuperheating of discharge gas for R-744.

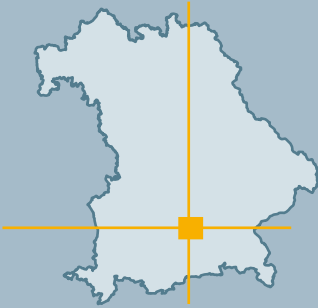


Schematic diagram of the refrigeration system

Below: Compressor and control panel
Left: Hops mill for the processing of hops at low temperatures

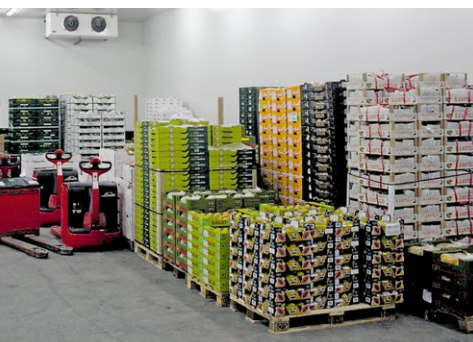


Wholesale Market Munich – ‘Fruits and vegetables stay cool’



Facts about the Facility

Location:	Großmarkthalle Munich, Schäftlarnstraße 9, 81371 Munich
Companies involved:	Friess GmbH, Günter GmbH & Co. KG, Frigoteam GmbH
Contact:	Mr Friess-Becker, c.friess@friess-klima.de, Rappstraße 18, 80687 Munich
Website:	www.friess-klima.de



Above: The delivery area for fruit and vegetables at the wholesale market in Munich

Below: The cold rooms for the storage of the products

Facility – Use, cooling capacity, refrigerant, refrigerant charge

The storage of fruit and vegetables requires a low, uniform temperature and a certain humidity to preserve the freshness of the product. The wholesale market in Munich comprises of cold rooms for this purpose. The brine combination refrigeration facility for these storage rooms is filled with the refrigerant ammonia-dimethyl ether (R-723). The plant, which was commissioned in 2010, has a refrigerant charge of 120 kg, and has a warm and a cold brine circuit. The cooling capacity of the plant is 385 kW for the cooling of four cold rooms and four storerooms in nominal temperature ranges from 2 to 10 °C. The refrigerant R-723 has a GWP of 8 and consists of 40% dimethyl ether and 60% ammonia.

Reasons for the transition to natural refrigerants

The decision in favour of natural refrigerants was made primarily for environmental reasons. In addition, the operator wanted to secure the long-term energy efficient operation of the refrigeration system. The return-on-investment period was relatively short, as the new plant is about 40% more efficient than the older system. The funding provided by the Federal Office for Economic Affairs and Export Control (BAFA) enabled the financing of the plant.

Technical Data of the Facility

Power required:	About 480 MWh per year for a space of 22,500 m ³ depending on the turnover of goods and occupancy of the warehouses
COP* summer/winter:	2.46
Costs:	Maintenance costs are about 4,500 € per year
Challenges:	Timely logistics planning required between placement orders and delivery of the various components. In addition, the work by various service providers such as sound insulation and floor work must be well coordinated.

*Coefficient of Performance

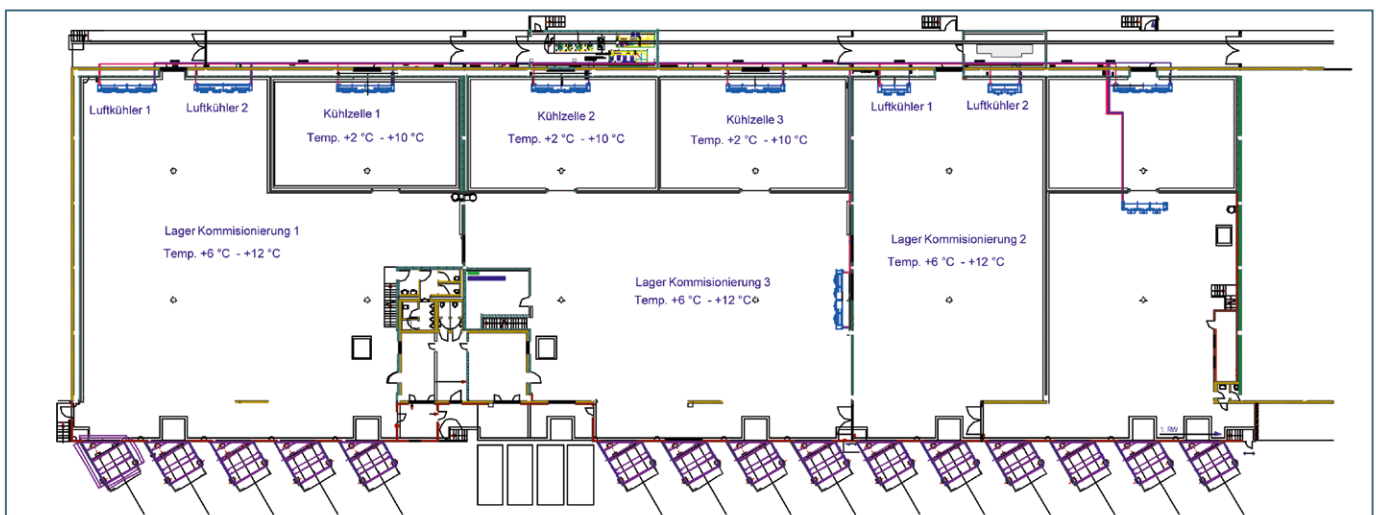
Special features of the facility

- The energy efficiency of the new plant is about 35 to 40% higher as compared to the old system.
- The largest potential for energy savings lies during the defrosting of cold rooms with 2 °C. This is carried out by the circulation of warm brine which is generated through the heat recovery of the refrigeration system. Defrosting is initiated via an on-demand defrosting regulator. The heat recovery process also provides heat for the cold rooms and hot water for washing the crates.
- Frequency inverters were fitted for the condenser fans, the compressor, ventilators and partially for the evaporator fan.
- Cold brine is circulated in the cold rooms through high performance ceiling air coolers with an integrated air-conditioning coil for the case of heating. These were suspended from a special steel construction in order to relieve the load off the ceiling.
- The aggregates were placed in a soundproofed room in order to protect the residential area nearby from noise.

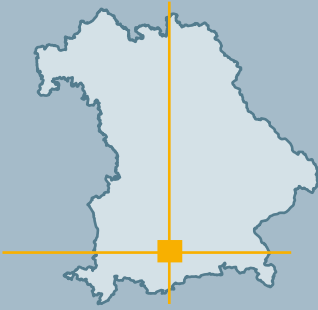
From left to right: the R-723 plant, the central control panel and the entrance to the soundproofed room in which the refrigeration plant is located



Plan of the cold rooms and storage rooms for fruit and vegetables in the wholesale market

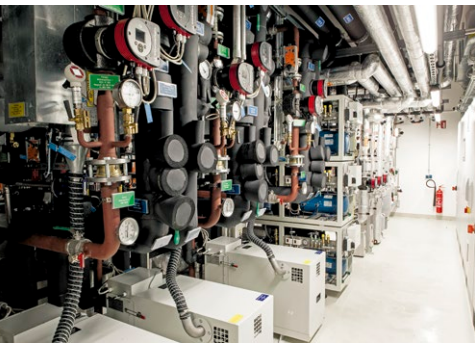


Roche – ‘Fluorinated gases will be replaced by natural refrigerants for all cooling processes’



Facts about the Facility

Location:	Roche Diagnostics GmbH, Nonnenwald 2, 82377 Penzberg
Companies involved:	Planning: IB Mayer AG Ottobeuren, Facility construction: WESKA Kälteanlagen GmbH
Contact:	klaus.matschl@roche.com
Website:	www.roche.de



Top: A refrigeration plant in one of the buildings at Roche in Penzberg
Below: The plant room for the refrigeration system

Facility – Use, cooling capacity, refrigerant, refrigerant charge

The focus of the activities of the Roche Group is the discovery and development of novel diagnostics and medicines together with their production. In Bavaria, Roche is represented in Penzberg and operates one of the largest biotechnology centres in Europe at this location. Reliable refrigeration technology is indispensable for the storage of feedstocks for production as well as for the bioengineered reagents for diagnostic tests and active ingredients – exclusively proteins – for medicines. Nearly all refrigeration systems are operated with natural refrigerants. Several large refrigeration plants with a capacity exceeding 20 MW are solely operated with the refrigerant ammonia (R-717). The temperature ranges lie between 3 °C (cold water) and –15 °C (cold brine). In addition, there are several refrigeration systems in the medium output range between 3 and 100 kW that have been operated solely with carbon dioxide (R-744) or propane (R-290) since 2005. One such plant is mentioned here as an example. The temperatures are in the range of 4 °C, –20 °C and –40 °C. For special applications at low temperatures (down to –90 °C) refrigeration systems are also operated with the refrigerant methane (R-170). For special cases absorption chillers are available.

Technical Data of the Facility

Power required:	About 65,000 kWh per year
Cooling capacity:	28 kW at a room temperature of –40 °C
Costs:	The maintenance and operating costs have remained about the same compared to the old systems with HFC refrigerants
Challenges:	It is important that well-trained service staff is available for refrigeration plants.

Reasons for the transition to natural refrigerants

A Roche Group directive from 1994 envisages that all substances required by the Group which damage the ozone layer or negatively impact the climate over a long period of time (HCFCs, CFCs, HFCs and PFCs) must be eliminated by 2015. In particular, these substances can be found in fire extinguishing systems, refrigeration systems and in process technology. The company would like to make a lasting contribution to environmental protection through this Group directive. This directive applies to all Roche sites globally.

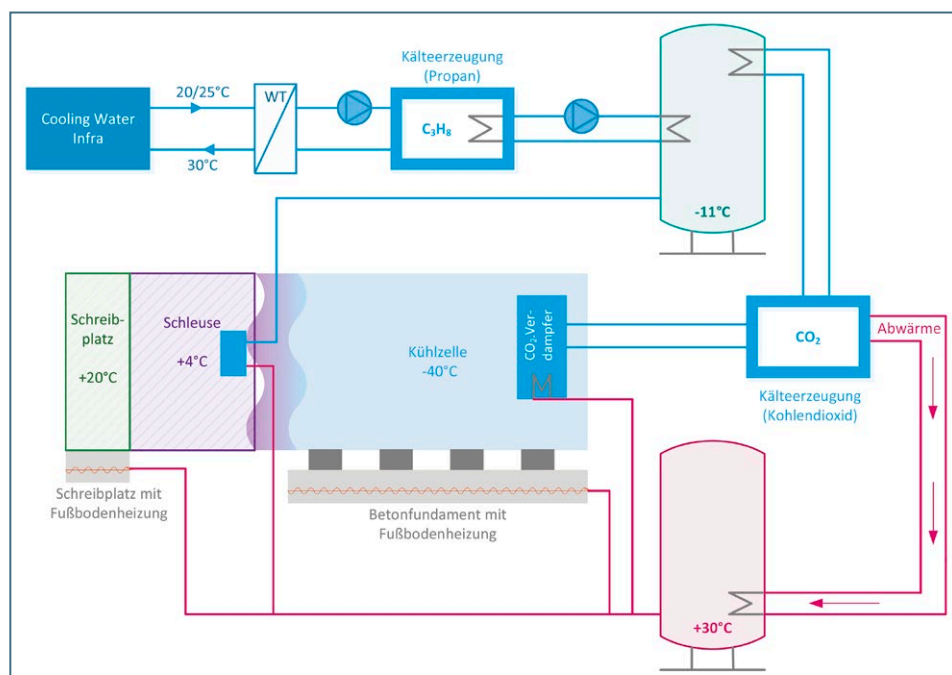
Special features of the facility

At Roche in Penzberg propane (R-290) and carbon dioxide (R-744) are used as refrigerants. The systems are generally divided into small compartments and connected to a secondary circuit. Owing to the compact compartments, which are equipped with a propane sensor and exhaust air vents, an explosion zone is not required in the equipment room.

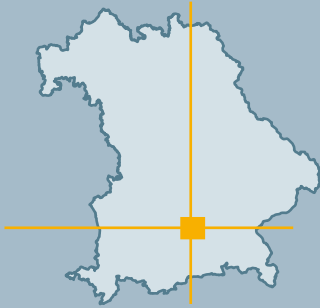
The R-744 facilities are particularly suitable for a low temperature range (-5 °C to -40 °C). In comparison to propane, carbon dioxide is non-flammable, and can thus be used as a direct expansion refrigerant. Due to the possible suffocation that could be caused by R-744 leaks, a gas warning system was built in the chilled room and in the control room, as required by the law. The plants were also equipped with a pressure compensating device or with high-pressure components owing to the pressure requirements of R-744. The backup of the system with low pressure causes the refrigerant to blow off when the system shuts down.

The condensation heat is used, for the most part, to defrost the evaporator and for heating purposes in the building. In addition, approximately 55% of the electricity demand of the refrigeration systems is covered by on-site photovoltaic installations. This is one of the measures that contribute to reducing energy consumption and to the sustainability of the site at Penzberg.

Right below: the direct expansion diffusers of the CO₂ plant for cooling the room and the smaller propane modules of the refrigeration system
Left below: Sketch of the cooling cycle with warm and cold flows for the cold rooms at -40 °C



Efficient Energy – ‘An intelligent, energy-efficient system with water as the refrigerant’



Facts about the Facility

Location: Various test locations in Germany
Contact: info@efficient-energy.com
Website: www.efficient-energy.com



A view of the assembly hall at Efficient Energy

Refrigeration Facility – Use, cooling capacity, refrigerant, refrigerant charge

Efficient Energy GmbH considers maximum energy efficiency as an essential contributor to climate protection: ‘Through innovative, technically intelligent solutions that convert energy more efficiently, a higher standard of living can be achieved globally and we can simultaneously manage existing resources cautiously.’ The product of the company, the ‘eChiller’, optimally implements the thermodynamic cycle with pure tap water as a refrigerant, built in a water chiller unit with centrifugal turbo compressors. The ‘eChiller’ operates with less than 50 litres and needs to be filled only once. With around 40 kW cooling capacity, the cooling requirements of data centres, chemical and pharmaceutical industries, food production and storage, as well as the air-conditioning of buildings can be covered both economically and ecologically.

Reasons for the transition to natural refrigerants

The ‘eChiller’ is a compact centrifugal compression chiller, which can save 50% of power as compared to conventional machinery and which solely uses environmentally friendly water (R-718) as a refrigerant. Water as a refrigerant is not affected by all the legal environmental and safety regulations that are associated with other refrigerants.

**Coefficient of Performance*

Technical Data of the Facility

Power required: With a constant cooling capacity of 40 kW over a year, the yearly electrical input required is 1.8 kW on average.

COP* summer/winter: 5 to 75

Costs: Due to the high energy efficiency and the use of water as a refrigerant, the operating costs are significantly lower than conventional systems. The payback is about three years.

Challenges: The system cannot provide temperatures below 0 °C and is designed for frost-free installation owing to the use of water as a refrigerant.

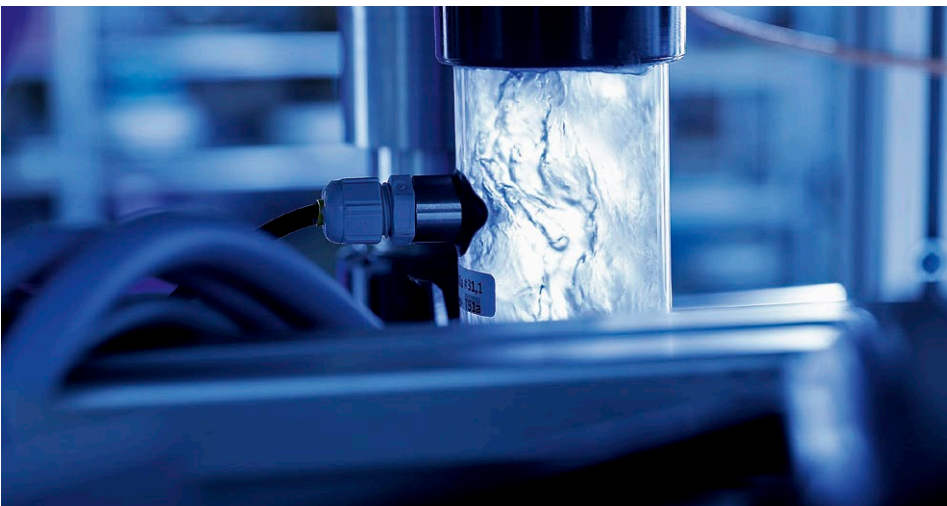


Special features of the facility

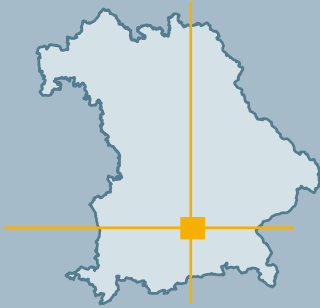
The realisation of the concept allows for a favourable energetic implementation of the thermodynamic cycle.

The challenge here is that within the relevant temperature range, water has a low saturation pressure of a few mbar. This results in a low density and thus, a large volume of vapour, which must be considered in the structural design of the plant components. Therefore, all the system components for the 'eChiller' had to be designed and integrated into the cooling module 'eTin'. In the 'eChiller' several 'eTins' are interconnected intelligently and allow for different operating conditions. This modular construction allows the parallel and serial combination of 'eTins', depending on the heat load and the outside temperature, for the operation of only those parts of the plant in order to achieve the required cooling capacity or to achieve the temperature change from the heat source to the heat sink. The transitions are fluid, ranging from two-stage full-load operation up to the free cooling operation. But unlike conventional refrigeration systems with 'free cooling', the internal passive cooling of the 'eChiller' switches on at higher ambient temperatures than at the cold water inlet temperature.

*The 'eChiller' produced by
Efficient Energy GmbH*



Lidl – ‘Use of propane as a natural refrigerant even at high ambient temperatures’



Facts about the Facility

Location:	Lidl Store, Dachauer Str. 380, 80993 Munich
Companies involved:	AHT Cooling Systems GmbH
Contact:	Mr Övünc Cinar, oevuenc.cinar@lidl.com, Lidl Stiftung & Co. KG, Stiftsbergstraße 1, 74167 Neckarsulm
Website:	www.lidl.com



Facility – Use, cooling capacity, refrigerant, refrigerant charge

The focus on the use of the natural refrigerant propane (R-290) for new refrigeration systems by Lidl has gained increasing importance. The firm and the company AHT have developed the new chiller cabinet technology ‘VENTO Semi-Plug-In’ which is designed to adhere to the limits set for propane in the standard EN 60335-2-89 (limit of 150 grams per cooling cycle of R-290). The system can be used without problems even in warmer climatic regions, where other natural refrigerants might be uneconomical to operate from the energy point of view. As an example for this brochure, the first generation of such a propane refrigeration system is described here for a Lidl store in Munich. In this system, the amount of refrigerant per refrigerant circuit is 700 g. The waste heat from the cooling process is discharged via an environmentally friendly external air cooled brine circuit, so that the total refrigeration required is limited only to the individual cooling racks in the shop. Moreover, it is possible to operate other units in the store on the brine-cooled circuit. This includes, for example, deep freezers and the cooling aggregates for chilled rooms. Another advantage of this systems technology is that it is possible to integrate a simple heat recovery, with which the store can be very efficiently heated.

Technical Data of the Facility

Power required:	51,000 kWh/annum (including lighting, 2–4 °C mean storeroom temperature / 31.25 lfm cooling rack / display area = 48.6 m ²)
COP*	
summer/winter:	For ambient temperature 10 °C = 5.5 / for 30 °C = 3.2
Costs:	Considerable economic benefits for acquisition and maintenance costs as compared to conventional refrigeration systems with central refrigeration.
Challenges:	The refrigerant charge of 700 g of propane (R-290) is difficult with regard to structural engineering approvals. This will be simplified in the future with a 150 g multi-circuit solution.
Award:	LEED Platinum for a Lidl Market in Denmark

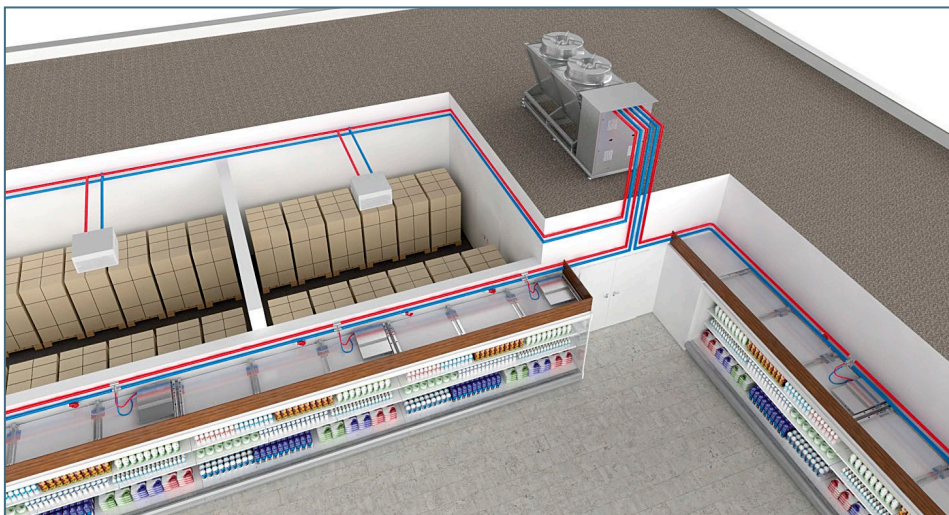
*Coefficient of Performance

Reasons for the transition to natural refrigerants

The food retail industry is dependent on reliable and energy-efficient cooling systems. Lidl has therefore set itself a medium-term target to exclusively use natural refrigerants globally; for the refrigeration equipment at new stores and in the modernisation of existing stores. One reason for the transition to natural refrigerants was Lidl's corporate strategy on sustainability, improving energy efficiency and reducing CO₂ emissions (TEWI-Value).

Special features of the facility

Since the limit of 150 g of propane per cycle had been exceeded, the certification of 'VENTO GREEN' units was carried out separately by TÜV Nord. In addition, verification by TÜV Süd was carried out according to the requirements of the Pressure Equipment Directive 97/23/EC, the 'Machinery Directive 2006/42/EC' and the standardised Norm EN 378-2.

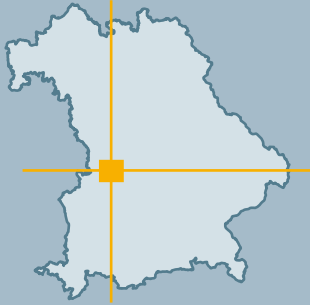


Left below: A schematic rendering of the supermarket with the refrigeration plant

Right: The refrigeration plant at the back of the supermarket surrounded by fencing



ALDI SÜD – 'Energy efficient and climate-neutral cooling'



Facts about the Facility

Location:	ALDI SÜD Store, Erlenweg 5, 86641 Rain/Lech (ALDI SÜD operates 500 other stores on CO ₂ -based cooling systems)
Companies involved:	Carrier Kältetechnik Deutschland GmbH
Contact:	Ms Agnes Schmitter, kaeltetechnik.mg@aldi-sued.de, Technical Consultant: tebeg Würzburg
Website:	www.aldi-sued.de/kaeltetechnik



Facility – Use, cooling capacity, refrigerant, refrigerant charge

The environmentally sound operation of stores is the focus of the energy management strategy of the corporate Group ALDI SÜD. The refrigeration systems of the Group integrate solutions for energy saving refrigeration equipment, climate-friendly refrigerants and permanent quality assurance of the existing cooling units.

Since 2010, new stores have been fitted out with refrigerated shelves and refrigeration plants which are operated with the natural refrigerant CO₂ (R-744).

ALDI SÜD operates transcritical CO₂ cooling systems in 500 stores in Germany. This makes up about 27% of all stores. In addition, CO₂ cascade systems are used as the higher-level stage of an F-gas system in some of the stores. Moreover, old refrigerating systems containing a refrigerant with high GWP, such as R-404A, are being continuously replaced by environmentally friendly and efficient CO₂ cooling systems.

Quarterly consultations on energy consumption and refrigerant losses are held with the suppliers. Each newly commissioned facility is technically proofed by an external service provider. The CO₂ refrigeration system of the ALDI SÜD store in Rain on the Lech serves as an example here. The plant has a refrigerant charge of around 120 kg and a cooling capacity of 48 kW.

Technical Data of the Facility

Power required:	The CO ₂ systems consume approximately 55,000 kWh each year depending on the size of the system.
COP*	
summer/winter:	Between 1.6 in summer and 6 in winter (excluding the recovered heat)
Costs:	The investment costs are slightly higher than F-gas systems while the maintenance costs are approximately the same. An advantage over F-gas systems is that the cost of the refrigerant R-744 is relatively low.
Challenges	Specialised staff and suppliers of transcritical CO ₂ systems are hard to find. Owing to the innovative technology one is dependent on especially innovative suppliers.

*Coefficient of Performance

Reasons for the transition to natural refrigerants

Since 2006, the ALDI SÜD Group has increasingly promoted the use of the alternative and natural refrigerant CO₂ and has tested the technical and economic efficiency of the systems in several pilot projects. The central goal, in addition to the increase in energy efficiency, being the optimisation of operational energy and service costs.

In the past few years, ALDI SÜD has been able to reduce its energy consumption by 50% as compared to analogously controlled conventional systems by investing in modern and environmentally friendly chillers.

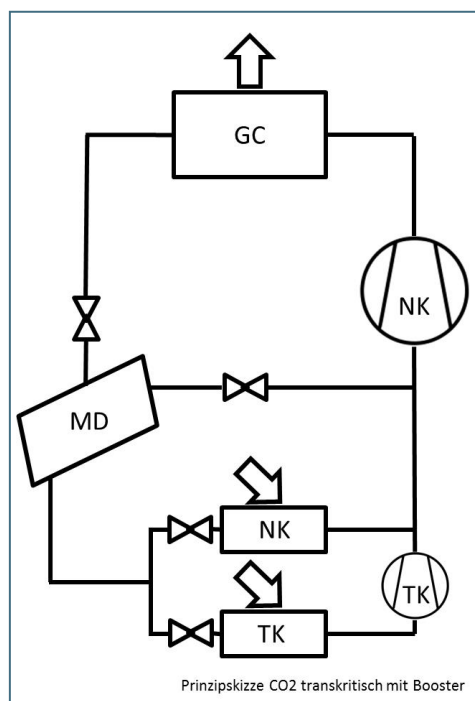
Today, four out of five freezer cabinets at ALDI SÜD are operated with the natural refrigerant propane (R-290). The company has set itself the goal of replacing the remaining freezer cabinets containing F-gas refrigerants with propane-powered chiller cabinets by the end of 2015.

Special features of the facility

The transcritical CO₂ systems at ALDI SÜD are equipped with a 'TK-Booster System' to supply the freezer areas. The system at the store in Rain on the Lech consists of three compressors for normal cooling, one of which is speed controlled by a frequency inverter. The compressor for the freezer operates efficiently at a further stage, in which it discharges its waste heat to the normal refrigeration cycle. This is referred to as the 'booster' system. In addition, efficient operation is ensured by a load-dependent optimisation of the evaporation temperature of all refrigeration areas. All gas coolers are equipped with energy efficient EC-fans and are thus speed controlled without stages. Transcritical CO₂ plants can, depending on the system, be operated safely even at high ambient temperatures.



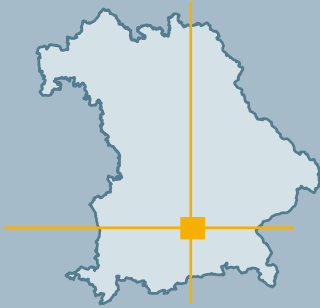
ALDI SÜD labels the cooling racks and cabinets which are operated with natural refrigerants with its logo 'Sustainable Cooling'



Left: A sketch of the CO₂ Plant
 Below middle: The central control cabinet
 Below right: The control cabinet and the compressors are placed in a compact box outside of the supermarket



Kaiser's Tengelmann – 'An effective combination: CO₂ and groundwater'



Facts about the Facility

Location:	Kaiser's Tengelmann Store, Hubertusstr. 1a, 82041 Oberhaching
Companies involved:	Erwin Merk GmbH
Contact:	bjawoscheck@ktmh.de
Website:	www.kaisers.de/unternehmen



Facility – Use, cooling capacity, refrigerant, refrigerant charge

The refrigeration system at the Kaiser's Tengelmann branch (grocery store) in Oberhaching near Munich is operated with the natural refrigerant CO₂ (R-744) and additionally uses groundwater as a gas cooler. The supermarket is centrally supplied with refrigeration through a CO₂ cycle. The CO₂ plant with a charge of 120 kg has a cooling capacity of 50 kW and cools 27 racks and 12 freezers in the store. The system can be relieved by cooling with groundwater, which is pumped up from 18 meters with a temperature of about ten to eleven °C. The groundwater can be used, for example, when the critical point of CO₂ (31 °C) is reached in the summer. Through the use of cool groundwater, not all the compressors need to be operated all year round in order to achieve the desired temperatures in the supermarket.



Technical Data of the Facility

Power required:	Approximately 80,000 kWh per year
COP*	
summer/winter:	2.24 (summer und winter)
Costs:	The plant was about 20% more expensive than a conventional F-gas system with R-404A. The maintenance costs of this plant are similar to those of an F-gas plant. The labour required for maintenance is lower, however the single components are currently more expensive than the spare parts for F-gas plants.
Challenges:	The high pressures initially posed a challenge.

*Coefficient of Performance

Reasons for the transition to natural refrigerants

The company Kaiser's Tengelmann pays attention to the economical use of resources and would like to actively contribute to climate protection. Since 2009, the company has been proactive in the field of climate-friendly cooling. In Germany, a total of 77 stores with cooling systems have been converted to natural refrigerants. All refrigerated racks and cabinets in the new branches are also equipped with doors to avoid cooling losses from open cabinets and racks. In order to optimise the energy efficiency of stores, refrigeration is connected to heat recovery.

Special features of the facility

- The energy consumption of the refrigerators and freezers connected in the store is visible through the real-time display. Fluctuations and error messages can be immediately reported to the maintenance company. Problems can often be remotely identified and resolved: For example, when the cooling or freezer room door is left open, the maintenance company recognises this on the basis of an error message and can immediately communicate this to the store manager.
- The highly efficient digital control technology enables the technician to maintain the cooling point temperature almost equal to the setpoint temperature. It also optimises the energy efficiency of the plant. Additional control and safety devices serve the stability of the refrigeration system and thus enable a smooth operation.
- Heat recovery is used for heating the store and for preparing hot water. A tube bundle heat exchanger was installed and plumbed on the primary side. In the heating mode, the heat exchanger is flooded on the secondary side. If the waste heat from the refrigeration system is not sufficient to heat the store, an additional heat pump is switched on.

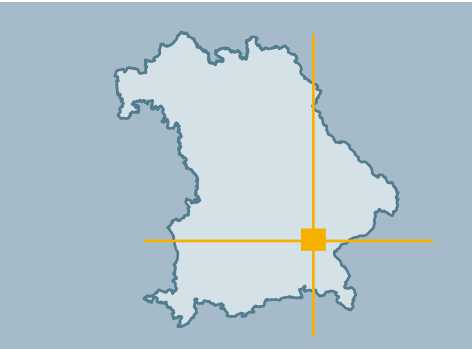


Left above: The flow of the refrigerant (R-744) is displayed on the piping

Right above: The plant room at the supermarket

Below: The compressors and the insulated piping of the refrigeration plant at Kaiser's Tengelmann

Edeka Lechertshuber & Wimmer – ‘Natural cooling for fresh groceries’



Facts about the Facility

Location:	Edeka Lechertshuber & Wimmer Store, Oderstraße 5, 84453 Mühldorf am Inn
Companies involved:	Staudinger Elektro- und Kältetechnik, R. Schiessl GmbH
Contact:	Mr Josef Wimmer, josef.wimmer@lechertshuber-wimmer.de, Mr Bernhard Staudinger, bernhard@team-staudinger.de
Website:	www.lebensmittelprofis.eu



Facility – Use, cooling capacity, refrigerant, refrigerant charge

For the reasons of environmental protection and future security CO₂ (R-744) has established itself as the standard refrigerant in new refrigeration facilities for the grocery chain Edeka. The refrigeration system that serves as an example here has been in operation since 2014 and has been installed in a Edeka-Lechertshuber & Wimmer branch in an existing building in Mühldorf on the Inn in Bavaria. The plant is a transcritical CO₂ system for low and medium temperatures and is operated as a booster system. The cooling capacity is 68 kW for plus-range cooling and 17 kW in the deep-freeze area. The refrigerant charge of the plant is approximately 220 kg of R-744.

Reasons for the transition to natural refrigerants

The company - Lechertshuber and Wimmer GmbH, operates 16 Edeka stores in Upper Bavaria and relies on energy efficient and environmentally friendly refrigeration technologies. In addition to the freshness and quality of the foodstuffs, the company pays great attention to energy consumption. New stores are equipped with refrigeration technology based on CO₂. The refrigeration systems of the older stores will gradually be retrofitted. In order to reduce energy costs even further, the company decided to exclusively use LED technology for the lighting in the cooling cabinets and racks as well as in the stores.

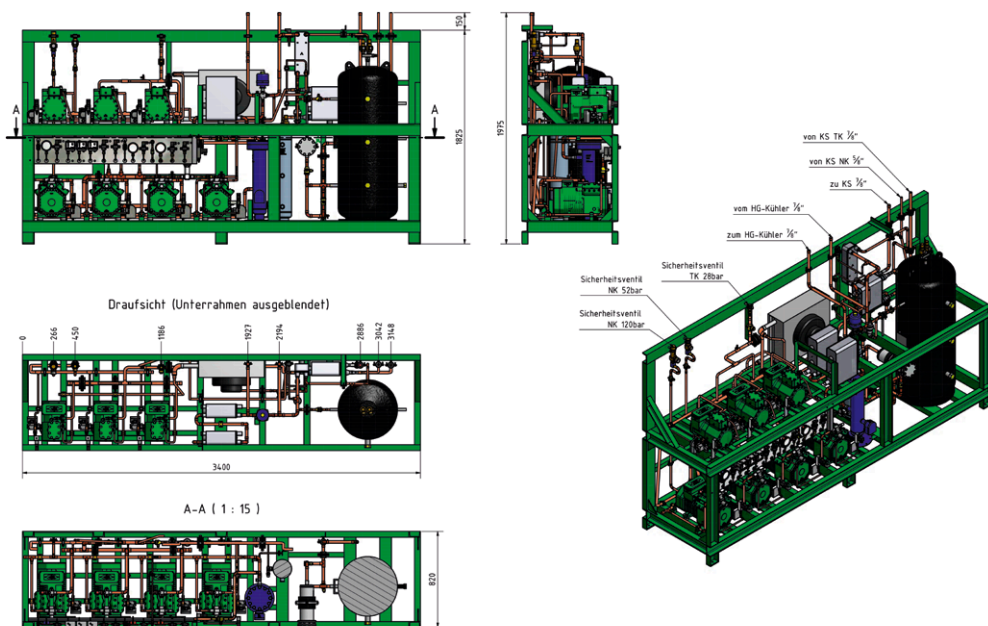
Technical Data of the Facility

Power required:	Approximately 262,000 kWh in the first year of operation
COP*	
summer/winter:	COP for the combined facility was 3.89 in the first year of operation
Costs:	The piping costs were lower. The refrigerant costs in the case of leakages are much lower as compared to F-gas containing refrigerants. In addition, costly and time consuming refrigerant disposal is avoided in the case of CO ₂ systems.
Challenges:	Some components were relatively expensive and not readily available at short notice for the first sub- and transcritical facilities. Some components require on-site clearance by the TÜV. Nowadays, the components are readily available and the control technology has matured.

*Coefficient of Performance

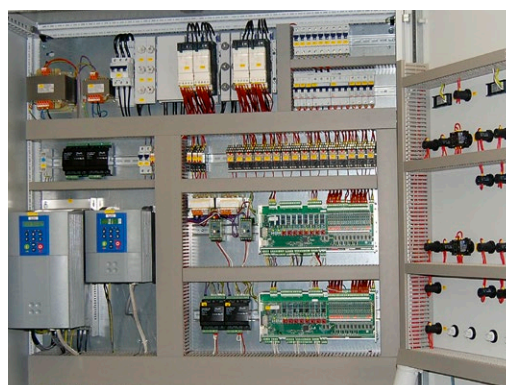
Special features of the facility

- The transcritical CO₂ system is designed in such a manner that it consumes as little electric power as possible. The following measures have been implemented in order to achieve this:
 - The leading compressors were each equipped with frequency inverters;
 - The Flash gas is sucked off with a parallel compressor at the pressure level of the collector;
 - The evaporators are equipped with electronic injection valves and EC motors. Even the hot gas cooler or condenser is equipped with EC motors.
- Heat recovery saves a lot of energy and the refrigeration circuit is optimised. Two heat exchangers were installed for two different temperature levels. The recovered heat is used for heating in the building via a ventilation system.
- A central control cabinet with controllers and remote maintenance software regulates and monitors the entire system. This allows the speedy detection and correction of any technical malfunction. In addition, every operational malfunction is reported to the refrigeration technician via SMS. Thus, problems in the cooling supply can be resolved promptly.

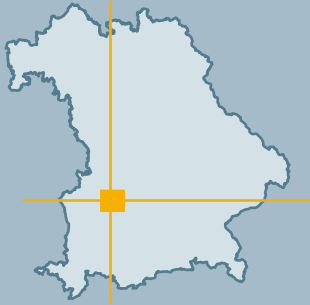


Left: A representation of the refrigeration plant

Below: The compressors (left), the central control cabinet (middle) and the scaffold on which the condensers are mounted (right)



Brewery Rapp – ‘Fresh beer requires good cooling’



Facts about the Facility

Location:	Brauerei Rapp KG, Augsburg Str. 14, 86500 Kutzenhausen
Companies involved:	ska GmbH
Contact:	Mr Rupert Rapp, rupert.rapp@brauerei-rapp.de
Website:	www.brauerei-rapp.de



The brewery Rapp is located in a landscape protected area in the district of Augsburg in Bavaria

Facility – Use, cooling capacity, refrigerant, refrigerant charge

The brewery produces various beers, juices and soft drinks at the plant in Kutzenhausen in the district of Augsburg. Reliable refrigeration is crucial for process cooling and for the maturation of beer. An ammonia plant (R-717) with a cooling capacity of 1,000 kW and a refrigerant charge of 1,600 kg covers the refrigeration needs of the brewery. The plant features air coolers with direct evaporation and a glycol circuit with Antifrogen L (propylene glycol) as a secondary refrigerant.

Reasons for the transition to natural refrigerants

The new plant came into operation in 2012, replacing four smaller R-22 chillers. The R-22 chillers were between 20 and 35 years old and energetically inefficient. In addition, due to the production ban on R-22 in the EU, the operation and maintenance of these refrigeration systems was no longer secured. Decisive for the choice of refrigerant ammonia (NH₃) was its environmental friendliness and the energy efficiency of the new plant.

Technical Data of the Facility

Power required:	916,500 kWh in the year 2014
COP*	
summer/winter:	4.0 averaged over the year for the entire plant
Costs:	Investment costs approximately 1,000,000 Euro, operating costs about 150,000 Euro per year
Challenges:	Long construction: The renovation of the system took about eight months as it was carried out parallel to the operation of the brewery. The switch of each refrigeration point could only be carried out successively, i. e. only after the previous refrigeration point was completed. Owing to the choice of stainless steel piping, slightly higher costs were incurred.

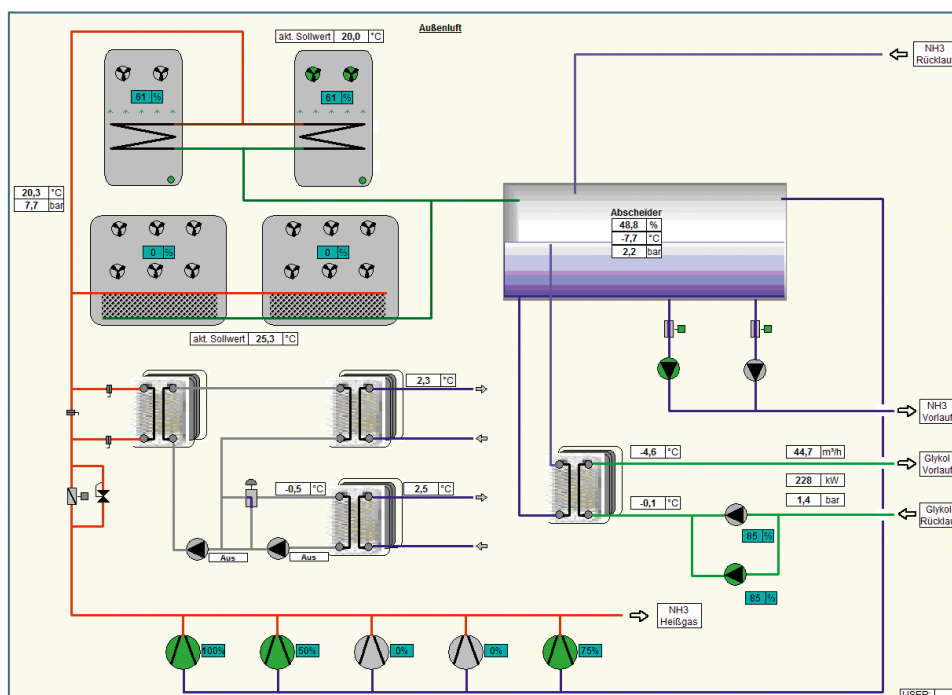
*Coefficient of Performance

Special features of the facility

- Evaporative condensers instead of air cooled condensers: The brewery installed evaporative condensers to increase the efficiency of the new plant through lower condensation temperatures.
- Conversion to a central refrigeration supply with efficient partial-load operation: The five compressors have power stages of 50, 75 and 100%, so that the cooling capacity is adjustable in increments of 50 kW. These levels provide a secure and effective partial-load operation. The compressors are switched on alternatively as required, so that the compressor with the lowest number of operating hours always operates through a load cycle circuit. In winter, sometimes only one machine is required for cooling, whereas in the summer up to four compressors run simultaneously.
- Frequency inverters for the evaporative condensers: The condensation temperatures are optimally controlled through the operation of the evaporative condenser fans via frequency inverters. Through the evaporation principle, the condensation temperature in the summer mode is lowered by an average of 10 °C as compared to the old system and thus the economical operation of the refrigeration system can be ensured.
- 25% heat recovery from the condensation heat: The waste heat from the high pressure side of the compressor is applied to various processes such as defrosting the air cooler or warming water for cleaning the transport vehicles.
- Almost 50% of CO₂ saved through the new technology: The new plant will emit around 15,800 tons of CO₂-equivalent within 15 years. The emissions of the old system over the same time scale were about 30,000 tons of CO₂-equivalent.



Above: The stainless steel piping with the markings showing the direction of flow of the refrigerant
 Middle: One of the compressors of the refrigeration plant
 Below: A view into the brewery storage room with the tanks



A schematic representation of the refrigeration plant of the brewery Rapp showing in green, the compressors that are in operation up to the respective loads (50, 75 or 100%)

Selected fluorinated and non fluorinated refrigerants with their respective GWP and ODP values

Category	Refrigerant	GWP*	ODP**
CFC (Chlorofluorocarbons, containing chlorine)	R-12	10900	1
HCFC (Hydrochlorofluorocarbons, containing chlorine)	R-22	1810	0,005
	R-401A	1182	0,033
	R-401B	1288	0,036
	R-402A	2788	0,019
	R-402B	2416	0,030
	R-408A	3152	0,024
	R-409A	1909	0,046
HFC/PFC (fully or partially fluorinated hydrocarbons, chlorine-free)	R-23	14800	0
	R-32	675	0
	R-134a	1430	0
	R-125	3500	0
	R-143a	4470	0
	R-404A	3920	0
	R-407A	2110	0
	R-507	3990	0

Category	Refrigerant	GWP*	ODP**
Natural refrigerants	R-170 (Ethane)	3	0
	R-290 (Propane)	3	0
	R-717 (Ammonia)	0	0
	R-718 (Water)	< 1	0
	R-744 (Carbon dioxide)	1	0
	R-600 (Butane)	4	0
	R-600a (Isobutane)	3	0
	R-601 (Pentane)	5	0
	R-601a (Isopentane)	5	0
	R-610 (Ethoxyethane)	4	0
	R-611 (Methyl formate)	25	0
	R-1150 (Ethylene)	4	0
	R-1270 (Propylene)	3	0
	R-723 (DME/ NH ₃)	8	0
HFO partially halogenated hydrofluoroolefins	HFO-1234yf	4	0
	HFO-1234z	6	0

* GWP: Global Warming Potential – Values calculated over a time scale of 100 years, from IPCC IV (2007)

** ODP: Ozone Depletion Potential

Further Information

Kyoto Protocol to the United Nations Framework Convention on Climate Change:

unfccc.int/kyoto_protocol/items/2830.php

Montreal Protocol on Substances that Deplete the Ozone Layer:

ozone.unep.org/en/treaties-and-decisions/montreal-protocol-substances-deplete-ozone-layer

Scientific reports on climate change and forecasts of global warming in different regions of the world:

ipcc.ch/index.htm

GWP values of refrigerants, determined by the Intergovernmental Panel on Climate Change (IPCC):

www.ipcc.ch/publications_and_data/ar4/wg1/en/ch2s2-10-2.html

European Regulation (EU) No. 517/2014 on fluorinated greenhouse gases:

eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014R0517&from=EN

Information of the European Commission on climate-friendly alternatives to fluorinated greenhouse gases:

ec.europa.eu/clima/policies/f-gas/alternatives/index_en.htm

Information of the Federal Environment Agency (Umweltbundesamt, UBA) on the EU Directive on fluorinated greenhouse gases:

www.umweltbundesamt.de/en/topics/economics-consumption/products/fluorinated-greenhouse-gases-fully-halogenated-cfcs

GIZ Proklima and its Green Cooling Network on natural refrigerants:

www.green-cooling-initiative.org/
www.giz.de/expertise/html/3372.html

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