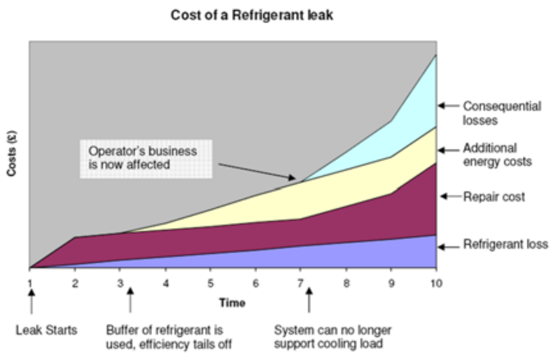
Financial, environmental, safety & reliability

Alternative Refrigerants & Leakage

Contents



Welcome to the REAL Alternatives Europe Blended Learning Programme

This booklet is part of a blended learning programme for technicians working in the refrigeration, air conditioning and heat pump sector designed to improve skills and knowledge in safety, efficiency, reliability and containment of alternative refrigerants. The programme is supported by a mix of interactive e-learning, printed training guides, tools, assessments for use by training providers and an e-library of additional resources signposted by users at www.realalternatives.eu

REAL Alternatives has been developed by a consortium of associations and training bodies from across Europe co-funded by the EU Lifelong Learning Programme, with the support of industry stakeholders. Educators, manufacturers and designers across Europe have contributed to the content. The materials will be available in Dutch, English, German, Italian and Polish.

Real Alternatives Europe programme modules:	
1.	Introduction to Alternative Refrigerants - safety, efficiency, reliability and good practice
2.	System design using alternative refrigerants
3.	Containment and leak detection of alternative refrigerants
4.	Maintenance and repair of alternative refrigerant systems
5.	Retrofitting existing systems with low GWP alternative refrigerants
6.	Checklist of legal obligations when working with alternative refrigerants
7.	Measuring the financial and environmental impact of leakage
8.	Tools and guidance for conducting site surveys

You can study each module individually or complete the whole course and assessment.

www.realalternatives.eu

Co-funded by: Lifelong Learning Programme

More information is available in the on line reference e-library. Throughout the text of each module you will find references to sources of more detailed information. When you have completed the module you can go back and look up any references you want to find out more about at www.realalternatives.eu/e-library. You can also add extra resources such as weblinks, technical manuals or presentations to the library if you think others will find them valuable. Module 5 provides a complete list of relevant legislation and standards referred to within the programme.

Register your interest in alternative refrigerants at www.realalternatives.eu to receive updates, news and event invitations related to training, skills and refrigeration industry developments.

Background to the programme and how it was developed. This leaning programme was developed as part of a two-year project led by a consortium of six partners from across Europe funded by the EU Lifelong Learning Programme. It was designed to address skills shortages amongst refrigeration, air conditioning and heat pump technicians related to the safe use of alternative refrigerants. It provides independent and up to date information in an easy to use format. The project consortium included training and professional institutes as well as employer representative bodies. Stakeholders drawn from employers, manufacturers, trade associations and professional institutes also contributed learning material, advised on content and reviewed the programme as it was developed. The six consortium partners were:

- Association of European Refrigeration Air Conditioning and Heat Pump Contractors
- Associazione Tecnici del Freddo, Italy
- IKKE training centre Duisburg, Germany
- Institute of Refrigeration, UK
- Limburg Catholic University College, Belgium
- London South Bank University, UK
- PROZON recycling programme, Poland.

Module 7 -

Measuring the Financial, Environmental, Safety and Reliability Costs of Alternative Refrigerant Leakage

This Guide (7 of 8) provides an introduction to evaluating the financial, environmental, safety and reliability costs of refrigerant leakage. It does not replace practical training and experience. Throughout the Guide you will find references to useful additional information from a range of sources that have been peer reviewed and are recommended technical guidance if you would like to find out more about these topics.

The following pages detail the costs of refrigerant leakage. A leaking system:

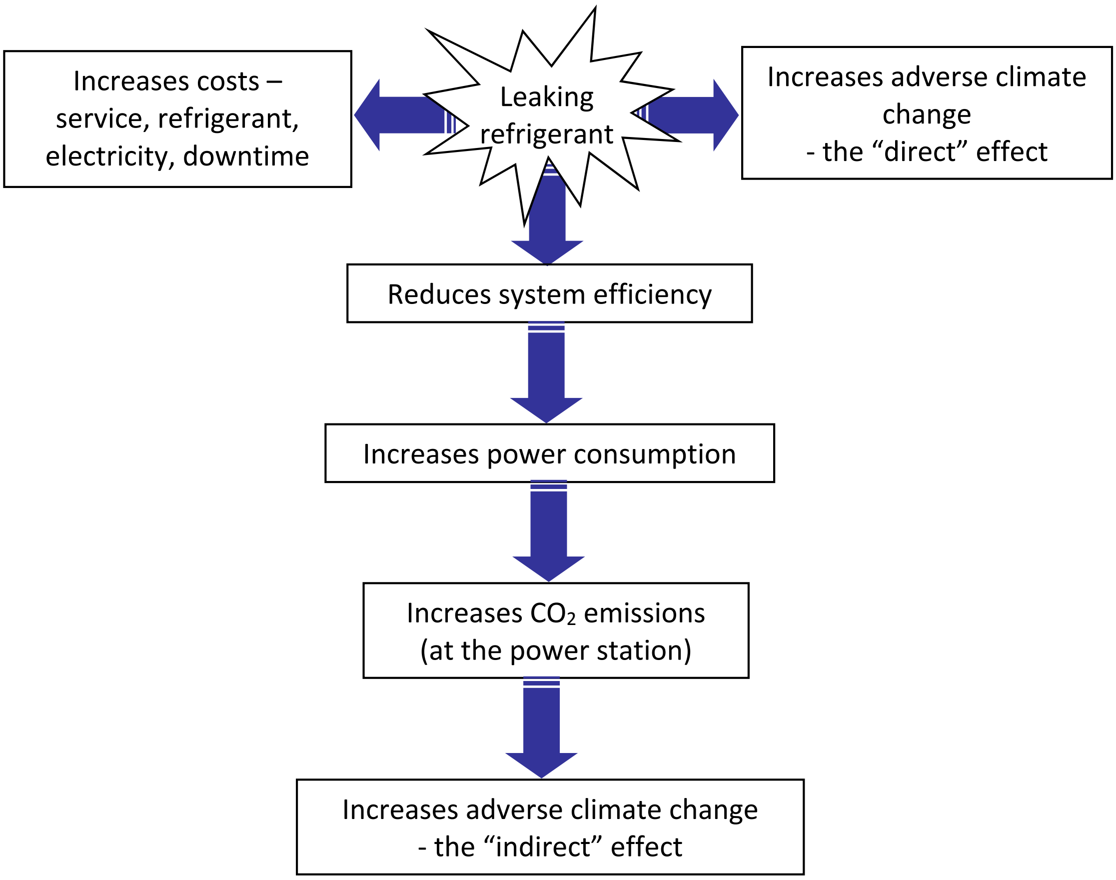
- Has a lower cooling capacity (and therefore the capacity may not meet the load);
- Can consume more power (which has an indirect environmental impact);
- Is less reliable (an undercharged system works harder and is therefore are more prone to failure);
- Is more hazardous – all refrigerants are asphyxiants, many alternative refrigerants are flammable and R717 is toxic.

Most alternative refrigerants have a low direct global warming potential, but the other impacts of leakage (e.g. on energy consumption) are similar to those for traditional refrigerants. So leakage matters and must be minimised whatever the refrigerant.

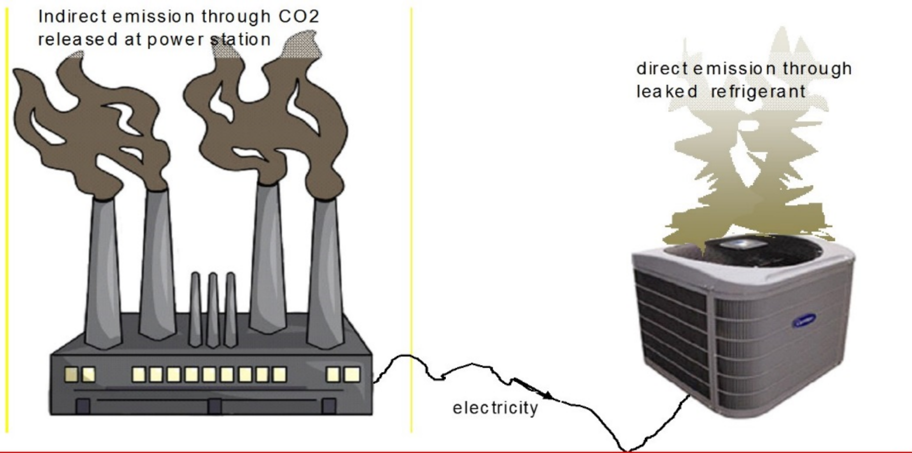
1. Environmental Impact of Refrigerant Leakage & RAC System Operation

Leaking refrigerant has a double impact on climate change:

- A direct effect if the refrigerant has a global warming potential;
- An indirect effect because of the increase in power consumption.



The total carbon emissions of a system include both the effect of leaking refrigerant and the power consumption of a system.



RAC contributes 10% of all worldwide GHG emissions.
8% through electricity use and 2% through leakage

The next section provides more information on this. In addition, the Total Equivalent Warming Impact (TEWI) is outlined in Module 1.

REAL Alternatives Guide 1 - Introduction

Global warming potential (GWP)

The global warming potential (GWP) of a refrigerant is a measure of how much a given mass of greenhouse gas (e.g. HFC refrigerant) is estimated to contribute to global warming. It is a relative scale which compares the gas in question to that of the same mass of carbon dioxide (whose GWP is by definition 1). A GWP is calculated over a specific time interval and the value of this must be stated whenever a GWP is quoted or else the value is meaningless.

Substances such as HFCs which have a high GWP tend also to absorb a lot of infra-red radiation and have a long atmospheric lifetime.

The GWP of alternative refrigerants is shown below:

	Type	Key facts	GWP (1)	Typical applications
R744	Carbon dioxide, CO_2	High pressures	1	Retail refrigeration, heat pumps, integrals
R717	Ammonia, NH_3	Toxic and mildly flammable	0	Industrial
R32	Hydro fluoro carbon, HFC	low flammable	675	Split air conditioning
R1234ze	Unsaturated HFC (aka hydro fluoro olefin, HFO)	low flammable	7	Chillers, split air conditioning, integrals
R600a	Isobutane, C_4H_{10}, hydrocarbon (HC)	high Flammable	3	Domestic and small commercial systems
R290	Propane, C_3H_8, hydrocarbon (HC)	high Flammable	3	Chillers, integrals
R1270	Propene (propylene), C_3H_6, hydrocarbon (HC)	high Flammable	3	Chillers, integrals

(1) GWP is from F Gas Regulation EU 517: 2014

GWP and carbon dioxide equivalency

Carbon dioxide equivalency is a quantity that describes, for a given mixture and amount of greenhouse gas, the amount of CO_2 that would have the same global warming potential (GWP), when measured over a specified timescale (generally, 100 years). The carbon dioxide equivalency for a gas is obtained by multiplying the mass (weight) and the GWP of the gas. The following units are commonly used:

- kg of carbon dioxide equivalents (kg CO_2e).
- tonnes of carbon dioxide equivalents (T CO_2e).
- million tonnes of carbon dioxide equivalents (MT CO_2e).

For example, the GWP for R290 (propane) over 100 years is 3 and for R32 is 675. This means that a leak of:

- 1 tonne of R290 is equivalent to emissions of 3 tonnes of carbon dioxide (T CO_2e).
- 1 tonne of R32 is equivalent to emissions of 550 tonnes of carbon dioxide (T CO_2e).

Calculating the environmental cost of leakage

The direct impact of leakage on climate change is calculated simply by multiplying the GWP of the refrigerant by the amount which has leaked in a given time. Two examples are shown below:

	Example A traditional HFC System	Example B system containing a low GWP refrigerant
Refrigerant	R404A	R32
Charge size	10kg	10kg
GWP	3922	675
Leakage recorded	Over a 12 month period 2 kg is added to both systems to replace refrigerant lost - Leakage rate is 20%	
Total Direct Impact	2 x 3922 = 7822 CO_2e	2 x 675 = 1350 CO_2e

Comparing refrigerant leakage to other environmentally damaging activities

It is useful to relate the impact of refrigerant leakage to other activities which impact on climate change, such as driving a vehicle. You need to know some key figures to be able to do this – these are provided in Appendix 1 of this Guide as typical figures for making carbon calculations.

This information allows you to compare the impact of climate change of refrigerant leakage to activities such as driving a vehicle, flying, running an appliance etc.

In Example B above the direct impact of 2kg of R32 leakage is 1350 CO_2e – this is equivalent to driving 6521 km in a car (assuming 0.207 of kg CO_2 per km for an average petrol car).

Indirect Impact

So far we have only considered the direct effect of leakage, not the indirect effect caused by less efficient operation which can happen when a system is under-charged. This is covered in the next section – it can be more significant than the direct impact for most of the alternative refrigerants.

2. Measuring the financial cost of leakage

It is very difficult to accurately calculate the total financial cost of leakage. The following contribute to the cost:

Table 1, typical refrigerant costs

Refrigerant	Typical cost € / kg
R744	3.75
R717	1.50
R32	7.50
R1234ze	37.50
R600a	9.30
R290	11.90
R1270	12.40

- Refrigerant – this is easy to calculate from the buying price of the refrigerant and the amounts used (note – buying prices vary significantly and depend on the discount provided by the supplier). As a guide typical costs are given in table 1;
- Cost of labour (and materials) to find and repair the leak and re charge with refrigerant – this should be easy to find from the service records but there will be a wide range as the work that needs to be carried out to fix a leak varies significantly depending on the location and magnitude of the leak and the type of system;
- Additional running cost of the system due to under charge of refrigerant – this can be very difficult to estimate as the profile of energy consumption vs. charge amount varies with different systems and there is very little practical data available. A simple example is given later in this section;
- Downtime and consequential losses – some end users have this information, but it varies significantly.

The costs will vary depending on how quickly the leak is found and repaired, as shown in the diagram below.

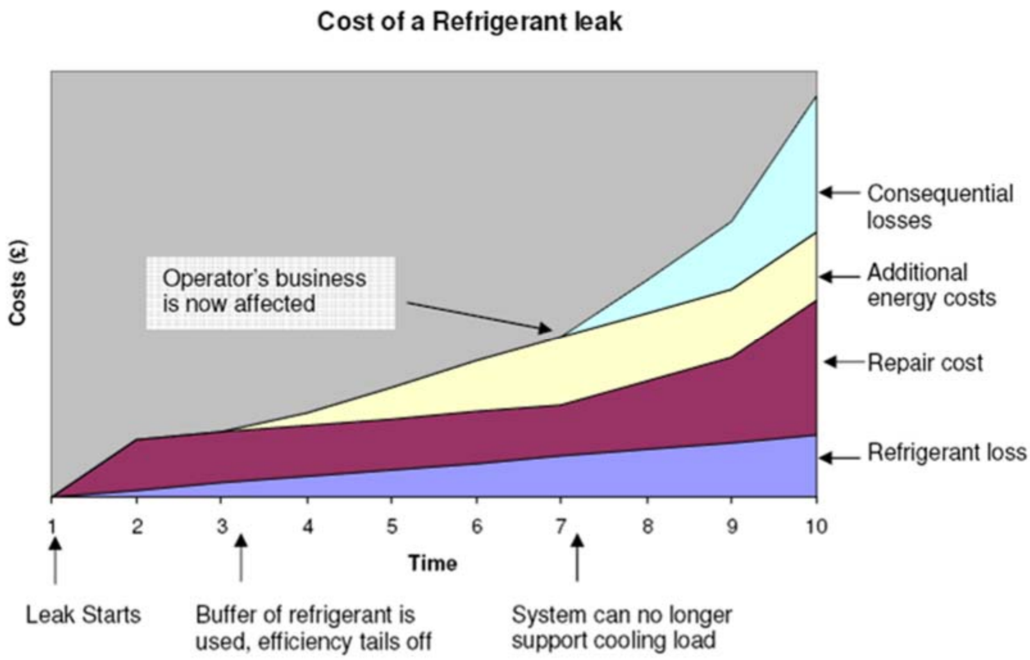


Figure 1, Cost of a refrigerant leak

System running cost

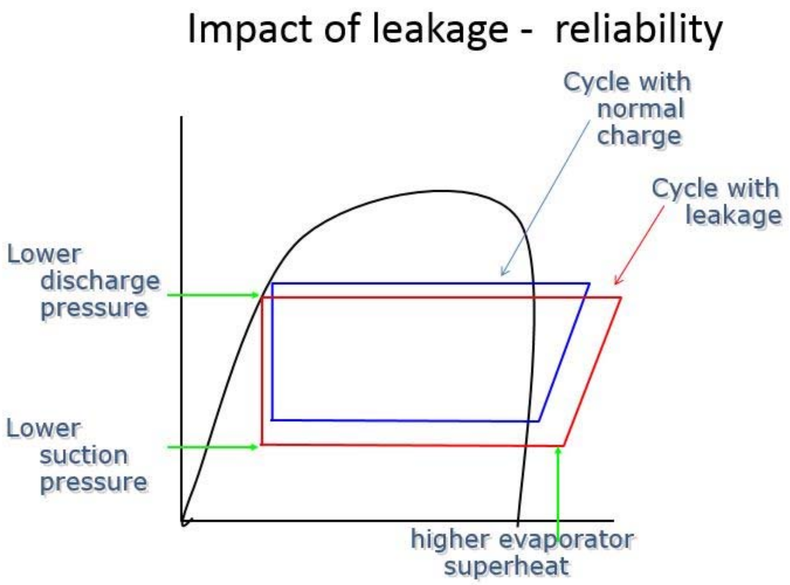
There is no simple correlation between leakage and energy efficiency - the impact of refrigerant leakage on energy consumption varies widely depending on the system as shown in the tale below.

System type	Impact of leakage
Small system with no liquid receiver (i.e. a critically charged system), e.g. many integral systems, split AC systems.	A loss of just 5% of the charge will reduce the efficiency because the refrigerant in the liquid line will be saturated rather than sub cooled, so less liquid refrigerant will flow into the evaporator. This reduces the suction pressure and the saturated evaporating temperature. A drop of just $1^{O}C$ in evaporating temperature will reduce efficiency (and increase electricity consumption) by between 2 and 4%.
Simple condensing unit evaporator systems with a liquid receiver, e.g. small retail systems, cold room systems, liquid chillers.	The receiver contains a buffer of refrigerant which is only required at extreme operating conditions (e.g. maximum load and maximum ambient). Once this buffer has leaked the effect is similar to that outlined above. The time taken to reach the critical charge will vary depending on the degree of leakage, load and ambient. While the buffer is leaking there is no effect on energy consumption (but there is a potential safety and environmental hazard).
Central plant systems with multiple compressors and evaporators, e.g. large supermarket systems, industrial plant.	As with the simple system above the receiver buffer will leak before there is an effect on performance. At this point the furthest evaporator from the pack will receive insufficient refrigerant and the solenoid valve will be open longer to get the desired refrigeration effect. As the leakage continues more evaporators will be starved. The effect is that the pack will run longer to provide the same cooling effect.

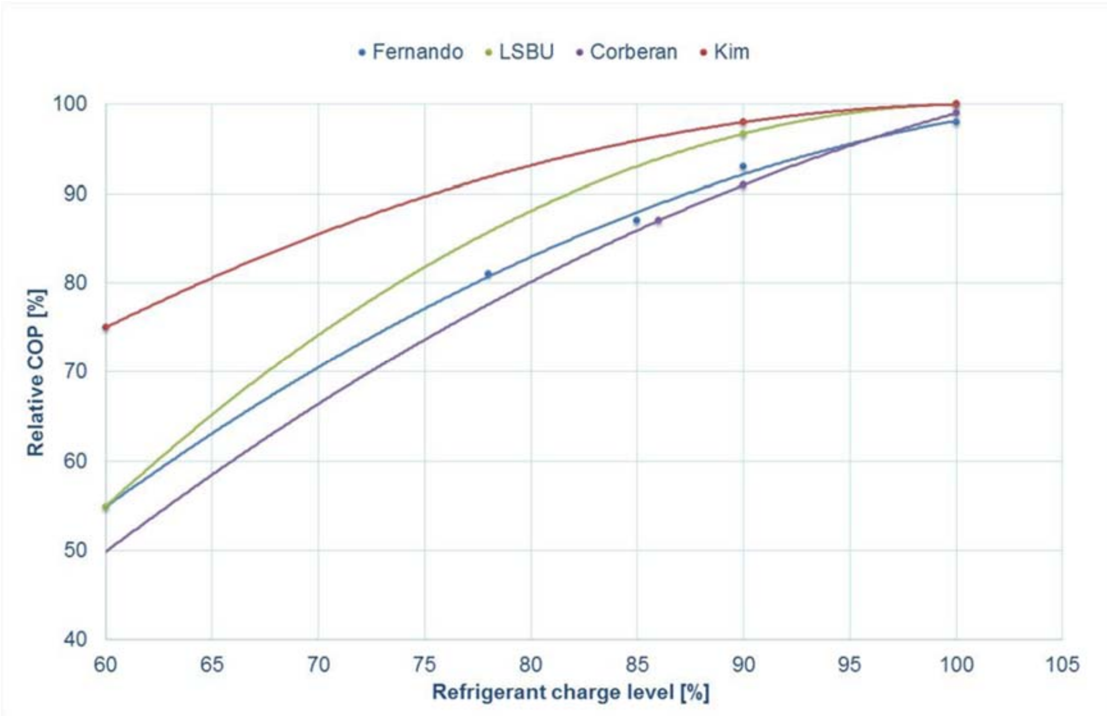
Figure 2, Impact of refrigerant leak on different types of system

Showing the impact of leakage on a pressure enthalpy chart

The Figure below illustrates how refrigerant leakage can affect system performance on a Ph Chart. It shows that leakage reduces discharge and suction pressure but increases superheat.



The following graph shows the impact of leakage on COP based upon a number of experimental studies. It can be seen that a 10% reduction in charge can reduce COP by 10%. In addition, there is an associated reduction in cooling capacity.



DECC Report on Impact of Leakage of Refrigerants from Heat Pumps, April 2014

Energy Costs Associated with Leakage

Example 1

The example below is for a simple single condensing unit single evaporator system. It is a low temperature cold room with a load of 10 kW. The system has the following operating conditions when fully charged:

- Evaporating temperature of -25^{O}C,
- 5 K useful superheat,
- -15^{O}C suction return temperature,
- 7K liquid sub cooling
- Condenser temperature difference (TD) of 10K.

The system performance is calculated in the table below:

	Fully charged system	Under charged system
Capacity, kW	12.9	**9.9**
Power input, kW	8.2	**8.0**
COP*	1.56	**1.24**
Annual running cost	**€5725**	**€6955**

*COP (Coefficient of Performance) is capacity / power input.

The above table includes the annual energy cost based upon full load operation for one year and an electricity cost of 0.175 euro / kW. The table also shows the relative cost of running an undercharged system at a reduced COP by 10%.

To accurately determine the increase in cost for a leak on this type of system you would need to know:

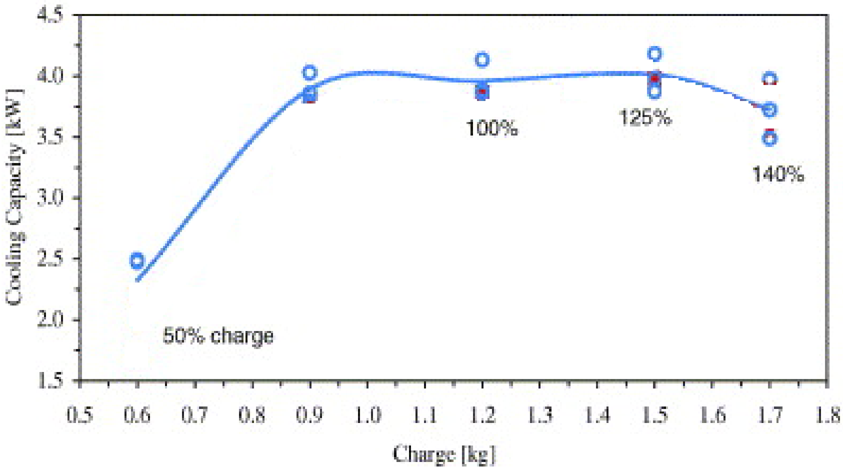
- Design operating conditions;
- Operating conditions when undercharged (this is likely to change as the leak continues);
- Length of time the system has been undercharged;
- Effect on operating conditions of under charge of refrigerant;
- System / compressor data, ambient temperature profile and load profile to calculate the performance and running cost of the system fully charged and under charged.

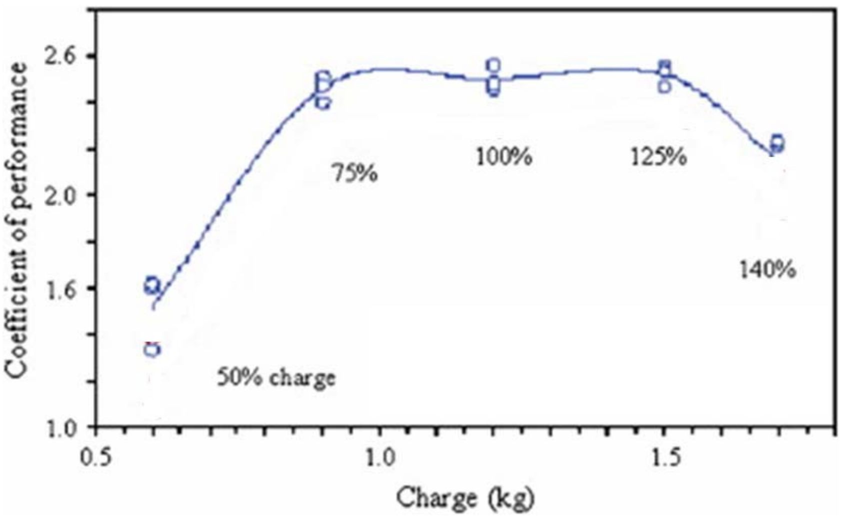
For many systems this information is not all available, but often an estimate can be made on the basis of that shown in the example above.

In addition, cooling capacity may be affected resulting in the system not meeting the cooling demand.

Example 2

The graphs below show the results of research on one system type to determine the effect of leakage on one system[1]:





Systems operate inefficiently for many reasons and there is often the opportunity to improve systems efficiency by simple, cost effective measures. These are outlined in five Guides available in the REAL Alternatives e-library.

Carbon Trust Guides for Owners of Refrigeration Equipment on Efficiency

In particular the following two guides will be helpful in reducing running costs of existing systems:

- Operational efficiency improvements for refrigeration systems;
- Results of site investigations.

[1] Graph modified from Grace, I.N., Datta, D. and Tassou, S.A. (2005), Sensitivity of refrigeration system performance to charge levels and parameters for on-line leak detection. Applied Thermal Engineering, 25 (2005), pp. 557–566

3. Safety

All alternative refrigerants are hazardous, so in the event of a leak there is a safety concern. The hazards associated with alternative refrigerants are summarised in the table below. More detailed information is provided in Guide 1.

REAL Alternatives Guide 1, Introduction

	Type	Key hazards
R744	Carbon dioxide, CO_2	Asphyxiant. High operating and standstill pressures. Contact with liquid or dry ice will cause freeze burns.
R717	Ammonia, NH_3	Toxic Mild flammability. Asphyxiant. Contact with liquid will cause freeze burns.
R32	Hydro fluoro carbon, HFC	Mild flammability. Asphyxiant. Contact with liquid will cause freeze burns.
R1234ze	Unsaturated HFC (aka hydro fluoro olefin, HFO)	
R600a	Isobutane, C_4H_{10}, hydrocarbon (HC)	Flammability. Asphyxiant. Contact with liquid will cause freeze burns.
R290	Propane, C_3H_8, hydrocarbon (HC)	
R1270	Propene (propylene), C_3H_6, hydrocarbon (HC)	

Gas detection should be used if a dangerous concentration can be exceeded in the event of a leak. For example:

- EN 378 Part 3 Clause 8 defines specific requirements for gas detection. Clause 8.1 states "Refrigerant detection systems shall be fitted in machinery rooms for refrigerants with ODP > 0 or GWP > 0 if the system charge is greater than 25 kg".

- For flammable refrigerants such as R717, R290 and R1270 leak detection must be installed to alarm and isolate at levels no greater than 20% of the LFL.

If a risk assessment identifies that a "dangerous concentration can be exceeded" - whether from a flammable or toxic perspective in any areas - ie machinery rooms or other spaces, particularly where people are present - gas detection must be installed.

It is important that this equipment is functional, and that its operation is checked periodically (e.g. annually).

4. Making a case for reducing leakage

Reducing leakage makes business, financial and environmental sense.

The benefits to business include:

- ☑ Compliance with legislation including the F Gas regulation;
- ☑ Improved "green" credentials;
- ☑ Reduced production down time / increased sales fixture availability / improved staff comfort as a result of improved reliability;
- ☑ Less health and safety risk from refrigeration or air conditioning – directly from refrigerant emissions and, for food applications, indirectly as a result of improved reliability.

In addition there are financial benefits:

- ☑ Less refrigerant cost;
- ☑ Less service cost;
- ☑ Lower costs associated with plant down time;
- ☑ No loss of energy efficiency associated with reduced refrigerant charge.

These costs may need to be offset against increased maintenance or some additional capital expenditure, but usually the difference is positive.

The environmental benefits are in parallel with the benefits identified above and include:

- ☑ More efficient operation of RAC systems and hence lower emissions of CO_2 at the power station;
- ☑ Lower emissions of greenhouse gases.

5. Tools for tracking refrigerant use

Real Alternatives Carbon Emissions Calculator

As part of this learning programme a Carbon Emissions Calculator Software and Refrigerant Leakage Log tool has been developed to record information about systems in an electronic format. The workbook can help system owners to meet the mandatory requirements of the F-Gas Regulations and provide refrigerant emissions and cost calculations for all refrigerants including alternatives.

The workbook includes:

- An electronic refrigerant leakage log for recording system parameters, refrigerant use, leak test and system repair data for up to 10 different systems.
- A calculator for Carbon equivalent emissions and costs that uses the logged data to estimate the impact of refrigerant use with information presented in graphical and tabular format. Up to date GWP figures are automatically included.
- A site summary report tool consolidating emissions data for all systems on the site on a single sheet.
- A graphical representation of refrigerant use that can be used to prioritize maintenance and leakage reduction actions

The freely available software tool can be downloaded from the REAL Alternatives website (www.realalternatives.eu)

A sample screen from the calculator showing refrigerant use in table and graph form is shown below. A demonstration video on how to use the spreadsheet tool is available in the REAL Alternatives e-library.

Video on Refrigerant Calculator in REAL Alternatives e-library

Menu - click to navigate (macros must be enabled)

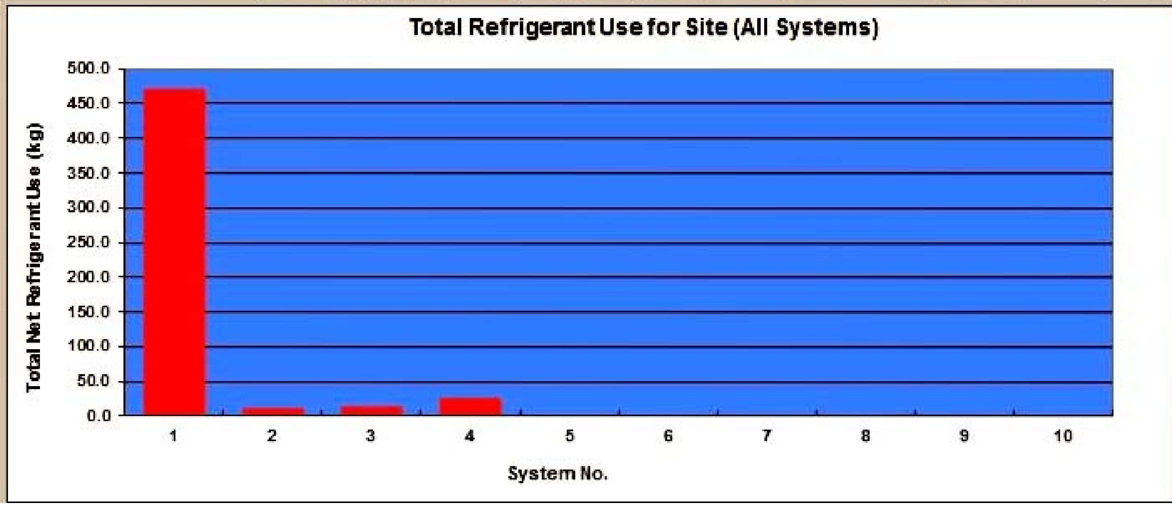
Refrigerant Leakage Log Data Sheet	Print	Save and Exit
Carbon Emissions and Costs	Total Refrigerant Use for Site	Data Sheet / User Guide

Refrigerant Leakage Log and Calculated Carbon Equivalent Emissions - Summary for Site

Plant/Site Name:	REAL Alternatives Europe		
Site Address:	Europe		
Postcode:	EU	Site Telephone Number:	+442086477033
Time Period Recorded:	From: 31/01/2008	To:	16/02/2014

			REFRIGERANT		TIME PERIOD			REFRIGERANT ADDITIONS			REFRIGERANT EMISSIONS	
System No.	Plant Name	Plant Ref. No.	Refrigerant Type	Refrigerant GWP (relative to CO2)	First Record Date	Latest Record Date	Period Covered (Years)	Total Net Refrigerant Use (kg)	12 Month Equivalent Use of Refrigerant (kg p.a.)	12 Month Equivalent Loss of Charge (% p.a.)	Carbon Equivalent of Lost Refrigerant (tonneCO2e)	12 Month Carbon Equivalent of Lost Refrigerant (tonneCO2e p.a.)
1	Chiller	RAE1	R22	1700	05/11/2011	16/02/2014	2.28	472.4	206.7	516.86	803.1	351.5
2		RAE2	R410A	1980	22/08/2008	10/04/2011	2.63	10.5	4.0	14.24	20.8	7.9
3	Food Store	RAE3	R404A	3922	31/01/2008	18/02/2011	3.05	14.9	4.9	19.53	58.4	19.1
4		RAE4	R717		01/03/2010	22/03/2011	1.06	26.0	24.6	14.05		
5												
6												
7												
8												
9												
10			R407C	1650	12/12/2013	12/12/2013		1.0	N/A		1.7	N/A
						Totals (all systems)		524.8	240.2		884.0	378.5

Time Period Covered by This Report (Years)	6.05
Carbon Equivalent of Refrigerant Emissions Over This Period (tonneCO2e)	884.0
12 Month Carbon Equivalent of Refrigerant Emissions (tonneCO2e p.a.)	378.5
Total Refrigerant Used Over This Period - All Systems (kg)	524.8
Total Entrained Mass of Refrigerant - All Systems (kg)	268.00
Total Refrigerant Charge Lost Over This Period - All Systems (%)	196%



Appendix 1, Fuel Conversion Factors

	Conversion to CO_2 (gross CV basis *)	
Fuel	**Units**	**Carbon Factor kgCO_2 / unit**
Grid electricity	kWh	0.537
Natural gas	kWh Therms	0.185 5.421
LPG	kWh therms litres	0.214 6.277 1.495
Diesel	tonnes kWh litres	3,164 0.250 2.630
Petrol	tonnes kWh litres	3,135 0.240 2.315

Petrol and diesel vehicles	**kg CO_2 / mile**	**kg CO_2 / km**
1.4 to 2 litre petrol engine	0.3442	0.2139
Over 2 litre petrol engine	0.4760	0.2958
Average petrol car	0.3332	0.2070
1.7 to 2 litre diesel engine	0.3027	0.1881
Over 2 litre diesel engine	0.4153	0.2580
Average diesel car	0.3185	0.1979

Mode of public transport	**kg CO_2 / passenger km**
Average bus and coach	0.0686
National rail	0.0602
Long haul international flight	0.1206
Short haul international flight	0.1071
Domestic flight	0.1911

* Emission factors are calculated on a gross calorific value (CV) basis as generally quoted by energy suppliers.

The information in these tables is for the UK and is from a Carbon Trust fact sheet CTL018, Energy and conversion factors published in 2008 available from http://www.carbontrust.co.uk/resource/conversion_factors/default.htm

There is no assessment associated with this Module.
This module is designed a list of essential information only.

5. What next?

The information in this guide is an introduction to evaluating the impacts of leakage. There is much more information in the documents highlighted in the links. Go to the on line reference e-library at www.realalternatives.eu/e-library to explore any additional information you may find useful.

You can now continue your self-study with one of the following **Real Alternatives Europe** programme Modules:

1. Introduction to Alternative Refrigerants - safety, efficiency, reliability and good practice
2. System design using alternative refrigerants
3. Containment and leak detection of alternative refrigerants
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