Food process refrigeration: Milk chilling

Large energy savings are achievable in many refrigeration systems, often by paying attention to design and operation. Examining the energy efficiency opportunities while approaching CFC/HCFC phase-out could transform essential change from a necessary expense into profitable action.

This guidance note has two primary purposes:

- To identify energy saving opportunities which can be implemented while addressing CFC/HCFC phase-out.
- To assist in the creation of a company strategy for managing CFC/HCFC phase-out.

Background

Scientific observations have shown that the concentration of ozone in the stratosphere is decreasing. This thinning of the ozone layer is thought to be caused by the release of volatile chemicals containing chlorine and bromine, particularly those which don't break down in the lower atmosphere. To prevent further damage, the Montreal Protocol was signed by all the major nations of the world. As a result, the production of CFCs and HCFCs, the fluids used in refrigerating machinery, is being phased out (see Table 1 and Table 2) and very shortly the only source of CFCs will be reclaimed refrigerant. The European Community and other governments are accelerating these phase-out schedules and as recent history shows, all revisions to the Montreal Protocol have been superseded by more stringent time scales. HCFC phase-out will almost certainly occur before the dates shown in Table 2.

Milk is typically stored in bulk tanks at temperatures of 4.4°C or below. To prevent freezing evaporating temperatures of direct expansion chillers are limited to between -4°C and -2°C. Where indirect systems are used evaporating temperatures can be lower. As a result R12 and R22 are common refrigerants while R502 and others are also used. Production of R12 and R502, both CFCs, is about to stop. It is therefore essential that managers address affected plant immediately. The phase-out date for R22 is not so pressing but a contingency plan should be created as insurance against acceleration of HCFC phase-out.

Table 1: CFC phase-out dates

	Production relative to 1986 consumption	
	EC	**Canada**
1.1.1994	85% cut	75% cut
1.1.1995	100% cut	
1.1.1996		100% cut

Table 2: HCFC phase-out dates

1996:	Freeze at 1989 HCFC consumption + A x [1989 CFC consumption] (ODP weighted)	
	EC (A=2.6%)	**Canada (A=3.1%)**
2004	35% cut	35% cut
2007	60% cut	
2010	80% cut	65% cut
2013	95% cut	
2015	100% cut	90% cut
2020		100% cut

Energy saving opportunities

The need to address CFC/HCFC phase-out in milk chilling process equipment presents an ideal opportunity to implement energy efficiency measures. Some savings can be achieved for little to no cost while others will require varying degrees of investment.

The main stages in assessing potential energy saving opportunities are (Figure 1):

- Audit existing refrigerating equipment
- Check controls and set points
- Reduce heat loads
- Improve defrosting
- Reduce refrigerant temperature lift
- Optimise compressor and system operation
- Institute planned maintenance

Audit existing equipment

The equipment audit is dealt with in detail in a later section (Managing CFC/HCFC phase-out). In brief it involves identifying all refrigeration equipment owned by a company and creating a central index or database of relevant information. This will assist in deciding the suitability of particular equipment for energy saving measures and in creating a strategy to cope with phase-out time scales.

Check controls and set points

Ensuring that controls are correctly commissioned is relatively cheap and easy to do. Temperature control bands which are too narrow can result in equipment operating more frequently than required and also leads to cycling, which can reduce energy efficiency. These problems can often be remedied by adjusting the control algorithm time constants. All thermostat set points should be checked.

Reduce heat loads

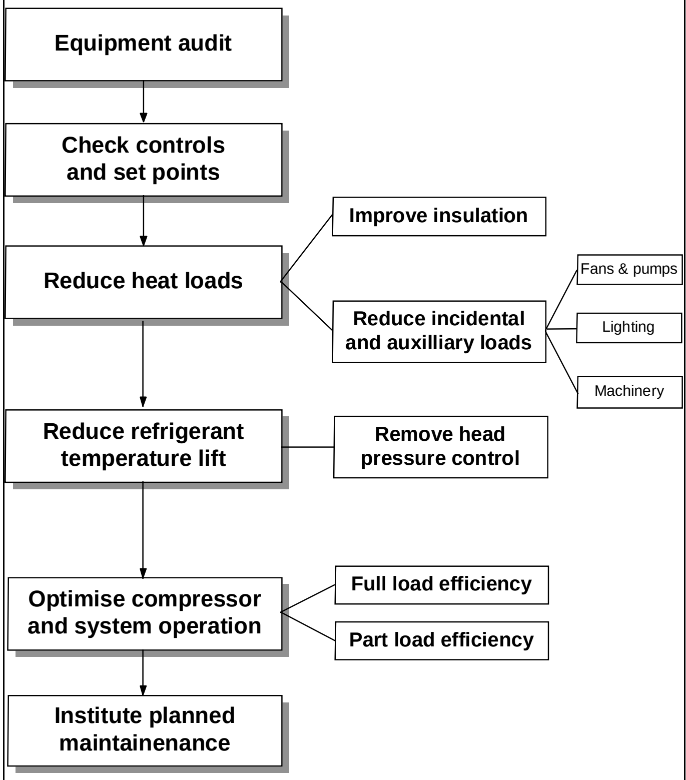
Any reduction in heat loads results in a reduction in required refrigeration capacity and therefore energy consumption. There are two main methods for reducing heat loads:

- Improving insulation.
- Reducing incidental and auxiliary gains.

- Insulation improvements

The walls of the milk storage tank space should be well maintained to guard against damage or degradation of the insulating material. The tanks are usually robust.

Figure 1: Optimising energy efficiency



- *Incidental and auxiliary heat gains*

High efficiency lighting such as high frequency fluorescent lamps should be fitted when the lighting system requires refurbishment. Care should be taken to ensure that the process room is not over illuminated; levels of 150 to 300 lux are generally satisfactory. The largest potential saving is from switching lighting off when it is not required. A variety of control systems are available including time clocks and delay-timers. Care must be taken to prevent an area being plunged into darkness while occupied and this may be achieved by having a permanent, but low level, of background illumination.

Where a secondary refrigerant is used, heat from the pump will add to the loading on the refrigeration system and also act to increase the temperature of the milk in the storage tank. The most efficient pump/motor combinations should therefore be used.

Improperly designed and operated regenerative pasteurisers can significantly increase energy consumption and leave chilling equipment with unnecessary work. By increasing the size of the regenerator the regeneration ratio can be increased and the chilling duty reduced. The capital cost of increasing the size of the heat exchanger can often be quickly recovered.

Reduce temperature lifts

The efficiency of refrigerating plant is dependent upon the size of the temperature lift between the evaporator and the condenser: the smaller the lift the more efficient the system.

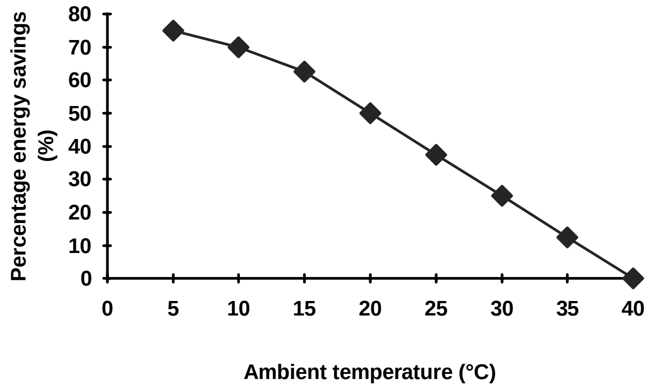
- *Head pressure control*

Many systems maintain a higher lift than is necessary through the use of head pressure control. This practice aims to maintain a high pressure in the condenser to ensure a controlled supply of refrigerant to the evaporator.

The control pressure can be reduced using a balanced port thermostatic expansion valve or an electronic expansion valve, while the installation of a liquid line pump can further reduce the need for such control. Lowering the control pressure allows the condensing pressure to fall as the outside temperature falls from the design condition and can improve energy efficiency by 50%, particularly during winter. The cost of these measures varies between C$300 and C$3,000 (£150 - £1,500) if installed at the time of refrigerant replacement and will normally pay back in about two years.

Figure 2 illustrates the energy savings which can be achieved following re-adjustment of a system initially set to maintain head pressure at a design day condensing temperature of 40°C (assuming an evaporating temperature of 0°C).

Figure 2: Energy savings from adjustment of head pressure control (schematic)



Optimise compressor & system operation

Where compressor capacity control is required then normally the most efficient method is to run compressors in parallel and to switch units on or off to achieve the desired refrigerating duty. Modern variable speed drives are also a fairly efficient option. All capacity reducing systems should be operated in conjunction with electronic expansion valves where possible as they provide better turn down than standard thermostatic valves.

The practice of reducing capacity by running all compressors at part load simultaneously, throttling the suction gas or passing vapour from the high pressure side directly to the compressor are all very inefficient and can increase energy consumption by up to 50%.

Institute planned maintenance

Systematic, regular maintenance is the best way to ensure that plant continues to run efficiently and reliably. It is desirable that a company wide maintenance programme is instituted following the equipment audit.

Managing CFC/HCFC phase-out

The deadline for manufacturers to cease CFC production is imminent. Organisations should begin appraising their refrigeration equipment and identify the options for change, before legislation forces their hand. Rushing decisions could lead to costs which might otherwise be avoided. A suggested strategy is given below and is shown schematically in Figure 3.

Appoint a responsible person

Someone within the organisation, preferably a manager, should be given the responsibility of co-ordinating and implementing an organisation-wide refrigerant strategy. This is essential if, for example, CFCs contained in existing equipment are to be managed effectively.

Audit equipment

Initially, identify all refrigeration systems and set up a central index or database. The following details should be entered for each system:

- System use
- System type (e.g. reciprocating, screw)
- Design capacity
- Manufacturer/supplier
- Model and serial number
- Peak load
- Current refrigerant
- Refrigerant charge
- Age and cost when new
- History (leaks, maintenance etc.)

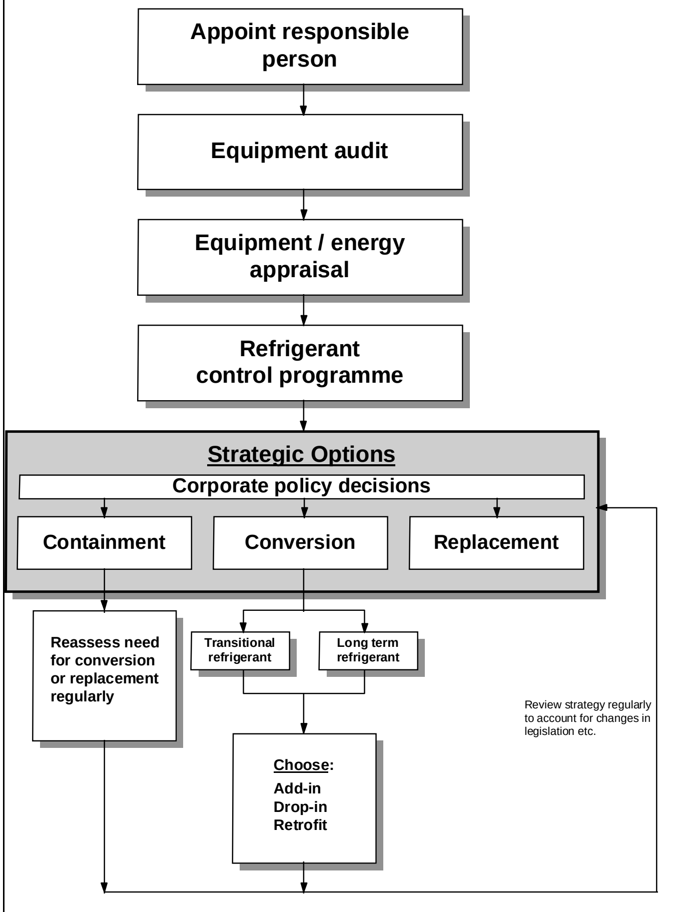
Appraise equipment

Each system should be appraised for:

- Need (is it essential?)
- Remaining economic lifetime:
  replacement may be the best option, even when retrofit is possible, for plant nearing the end of its useful economic life.
- Current over capacity:
  switching to some new refrigerants may result in a reduction in system capacity. Typically, refrigeration plant is oversized; it is important to know the degree of over capacity.
- Energy efficiency:
  opportunities for improving equipment efficiency should be identified. Equipment with a high potential for energy saving should be prioritised within the phase out strategy, while equipment with low efficiency should be considered for total replacement. Where an organisation has CO_2 emissions targets it may impose minimum plant efficiencies. In some cases, retrofitting a new refrigerant may result in reduced plant efficiencies, enhancing the economics of total replacement.
- Cost of conversion.
- Cost of replacement.

These options may be limited by the corporate policy decisions discussed below.

Figure 3: CFC and HCFC Phase-out strategy



Implement refrigerant control programme

Having a central refrigerant database and a responsible manager allows the existing refrigerant 'bank' to be effectively managed. Refrigerant from decommissioned plant can be recycled for use in other equipment. A corporate policy should be developed to ensure regular maintenance, leak checking and adherence to good refrigeration practice.

Strategic options

An organisation must make a number of strategic decisions regarding its approach to existing equipment. These are outlined below:

- Corporate policy decisions

An organisation must decide at an early stage on its internal and public stance with regard to certain political issues and equipment performance criteria. For example, should they:

- choose global warming potential (GWP) or total equivalent warming impact (TEWI) as the basis for calculating contribution to global warming?
- use transitional refrigerants in the knowledge that they are not seen as environmentally friendly and will be phased out in the near future?
- set minimum acceptable standards for energy efficiency?

The options available for dealing with existing equipment, guided by the corporate policy decisions, are principally:

- Containment
- Conversion
- Replacement

- Containment

Containment, or ensuring that refrigerant remains within the equipment, often involves not interfering with sound plant and should always be the first strategic choice where possible; it will almost certainly be the cheapest, especially for small hermetic systems. However, containment is not an excuse for inaction. Leak detection should be installed where it is appropriate and contingency plans should be developed to ensure there is an adequate supply of refrigerant for servicing and to allow future conversion or replacement should this become necessary.

- Conversion

A history of refrigerant leakage would make a policy of containment unsuitable. Given that economics (e.g. remaining lifetime, conversion cost) do not favour replacement, then conversion will be the strategic choice for the majority of refrigerating equipment. There are a large number of alternative refrigerants available to replace existing CFCs and HCFCs and it is the shear choice which is daunting.

Milk storage refrigeration is dominated by R12 and R22 equipment, with R502 equipment in use in some applications. Conversion from R12 is considered in this guidance note. Figure 5a lists the performance data of many R12 alternatives at evaporating temperatures of -5°C while Figure 5b lists R22 and its alternatives[1]. These tables are ***not*** exhaustive, but do list most of the alternatives currently manufactured by the major refrigerant producers. Table 5a gives the actual performance details of R12 and the performance of the other refrigerants with the COP and SCD (shaded area) shown ***relative*** to R12. They show that there is little to separate any of the alternatives in terms of efficiencies and working pressures, however discharge temperatures of some alternatives are around 10-15°C higher than R12.

The process for choosing an alternative can be simplified by following the decision tree shown in Figure 4. The tree follows simple logic:-

1. The new refrigerant should, if possible, have long term availability. This is insurance against phase-out time scales being moved forward for transitional refrigerants.
2. Where drop-in refrigerants are available they should be used - this will minimise cost and disruption.
3. Where a long term drop-in is not available a transitional drop-in should be used in place of a long term retrofitable refrigerant. This will delay the need for costly system modifications.

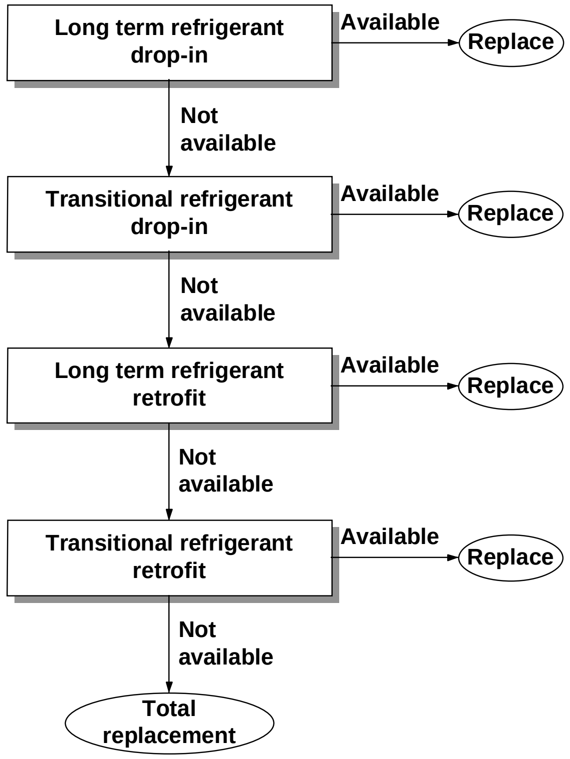
   This gives the following priority:

   - Long term drop-in
   - Transitional drop-in
   - Long term retrofit
   - Transitional retrofit

   Where no alternative refrigerant is available total equipment replacement will be necessary.

[1]These tables are based upon information available at the time of compilation of this information sheet. It is acknowledged that new refrigerants will become available in the future.

Figure 4: Choosing an alternative refrigerant



Applying the logic of Figure 4 to the table of R12 alternatives in Figure 5a gives the following results (the following logic could equally be applied to R22 and its alternatives in Table 5b):

Long term drop-in replacements:

There are no refrigerants in this category.

Transitional drop-in replacements:

- FX56
- FX57
- G2015
- MP39
- MP66

The list above shows a selection of transitional drop-in refrigerants available. However, apart from G2015 and MP39, the rest are intended for low temperature use (manufacturers' information). Strictly, G2015 is an add-in and so is easier to install than a drop-in. MP39 is not a true drop-in and requires a single oil change to a POE or alkyl benzene oil. It will also give discharge temperatures which exceed those of R12 by about 10°C.

Long term retrofit replacements:

- R134a

Where none of the above are suitable, R134a should be the next choice. It is the only refrigerant in this category and is the manufacturers' favoured choice in many applications (although not necessarily the best option) being suitable for most R12 applications. Use of R134a will generally require system modifications and oil flushing.

Transitional retrofit replacements:

There are no refrigerants in this category.

- Replacement

Total equipment replacement should be seen as the final option - but will be necessary when containment and conversion are not feasible. The complexity and cost of conversion can vary dramatically between different plant types and often depends largely on whether a drop-in refrigerant is available. Conversion can be very expensive and even when it is possible economics may favour replacement (e.g. when equipment is nearing the end of its useful life).

Although replacement represents an expensive choice, it does allow the use of new refrigerating plant designed specifically for use with alternative refrigerants and optimised for energy efficiency. For example, some new refrigerants are intended for use exclusively in new equipment and heat exchanger performance can be optimised for use with non-azeotropic refrigerant mixtures by taking advantage of temperature glides to achieve greater energy efficiency.

Education

The handling of many new refrigerants and oils differs significantly from traditional techniques. It is imperative that staff are trained to work with the new materials. Reduced efficiencies and plant failures can arise from incorrect procedure being followed, particularly where refrigerant replacement is being carried out. Advice regarding training and registration can be obtained from the HRAI in Canada (Tel: 010 1 (905) 602 4700) and the HEVAC Association in the UK (Tel: 44 (6285) 31186).

Figure 5a: Performance of R12 alternatives*

Refrigerant	**R12**	**R134a**	**MP39**	**MP66**	**FX56**	**FX57**	**G2015**
ASHRAE No.	R12	R134a	R401A	R401B			R405
Manufacturer	many	many	DP	DP	EA	EA	GT
Status		Long term	Transitional	Transitional	Transitional	Transitional	Transitional
Drop-in		No	Near**	Near**	Yes	Yes	Yes
Retrofit		Yes	-	-	-	-	-
Available		Yes	Yes	Yes	Yes	Yes	Yes
	Tev (°C)	**Tev (°C)**	**Tev (°C)**	**Tev (°C)**	**Tev (°C)**	**Tev (°C)**	**Tev (°C)**
	-5	**-5**	**-5**	**-5**	**-5**	**-5**	**-5**
SCD (dm^3/kJ)	0.56	1.01	0.86	0.81	0.88	0.83	0.83
COP	3.52	0.98	0.99	0.99	0.98	0.98	0.94
Pev (bar a)	2.61	2.43	2.88	3.07	2.78	2.98	3.27
Pco (bar a)	9.60	10.1	11.3	12.0	11.2	11.8	12.7
Tdis (°C)	65.0	61.9	76.4	78.4	79.4	79.8	64.4

Figure 5b: Performance of R22 alternatives*

Refrigerant	**R22**	**R717**	**R134a**	**Klea 66 AC9000**
ASHRAE No.	R22	R717	R134a	R407C
Manufacturer	many	many	many	ICI/DP
Status	Transition	Long term	Long term	Long term
Drop-in		No	No	No
Retrofit		No	Yes	Yes
Available		Yes	Yes	Yes
	Tev (°C)			
	-5	**-5**	**-5**	**-5**
SCD (dm^3/kJ)	0.35	0.93	1.63	1.03
COP	3.45	1.01	1.00	0.97
Pev (bar a)	4.21	3.55	2.43	4.21
Pco (bar a)	15.3	15.6	10.1	16.5
Tdis (°C)	82.8	147	61.9	75.6

*Tco = 40°C
** A single oil change to a polyol ester or alkyl benzene type is recommended.

Key:
RP: Rhone-Poulenc, C: Calor, DP: Du Pont, EA: Elf Atochem, GT: Gu Thermotechnology

Note:
The shaded area gives the performance of alternative refrigerants relative to R12 at the same evaporating temperature.
∴ To find the COP of MP39 at Tev= +5°C, COP= 4.78*0.96 = 4.59

Legend

SCD: specific compressor displacement
COP: coefficient of performance
Pev: evaporating pressure
Pco: condensing pressure
Tdis: discharge temperature

*Tco = 40°C
** A single oil change to a polyol ester or alkyl benzene type is recommended.

Key:
RP: Rhone-Poulenc, C: Calor, DP: Du Pont, EA: Elf Atochem, GT: Gu Thermotechnology

Note:
The shaded area gives the performance of alternative refrigerants relative to R12 at the same evaporating temperature.
∴ To find the COP of G2015 at Tev= -5°C, COP= 0.94*3.52 = 3.31

Legend

SCD: specific compressor displacement
COP: coefficient of performance
Pev: evaporating pressure
Pco: condensing pressure
Tdis: discharge temperature

Case study - Refrigerant retrofit

A milk storage tank has been successfully converted from R22 to R407C, an HFC with expected long term availability into the future. The system comprised of two bulk storage tanks fitted with two refrigeration units running in parallel. The units used Prestcold compressors with air cooled condensers. One system was converted to R407C while the other was left running on R22 for reference.

The retrofit was carried out using the now well documented procedure for converting to R134a. The original mineral oil was removed and replaced with a POE oil of equivalent viscosity. Filter drier cores and seals were changed to those compatible with R134a. The system was then run for a number of hours before removing the oil and replacing it with a fresh charge of POE oil. This procedure was repeated until the concentration of mineral oil in the POE oil fell below 1% (3 flushes). The R22 was removed from the system and the R407c was added in the liquid phase.

The converted chiller was able to pull down the temperature of the milk in the tank faster than the R22 reference indicating a larger refrigerating capacity. It also maintained lower milk temperatures once an equilibrium temperature had been reached. With power consumption also being slightly higher, the COPs of the two systems were very similar. It is worth noting that the discharge temperature of the R407C system was around 15°C lower than the R22 system. Several months of trouble free operation have now been experienced.

Case study - Energy efficiency

Regenerative pasteurisers are very common in the milk processing industry. The pasteuriser heat load can be 50% of the total cooling load if a poor regeneration ratio is used. In one case a dairy had a shortage in chilled water capacity arising from plant expansion. The dairy was quoted £150,000 by a refrigeration contractor to install new refrigeration equipment. However, process analysis revealed that the pasteuriser regeneration ratio was very poor and that the shortfall in cooling capacity could be provided by improving the ratio at a capital cost of just £25,000. In addition to the capital cost saving of £125,000 the cheaper investment also saved electricity worth £10,000 per year. The changes to the regenerator would therefore have had a simple payback of only 2.5 years and would have been a good investment even if the increase in capacity had not been necessary.

Abbreviations and definitions

CFC	(chlorofluorocarbon)	Refrigerants containing chlorine. Have high ODP and high GWP. Widely used as refrigerants
HCFC	(hydrochlorofluorocarbon)	Contain chlorine, but have lower ODP than CFCs. Wide range of GWPs.
HFC	(hydrofluorocarbon)	Contain no chlorine so do not attack ozone. Some have high GWPs
Add-in		A refrigerant which can be added to equipment without removing the existing refrigerant. No modifications required.
Drop-in		A refrigerant which can be used in equipment without the need for significant changes. The existing refrigerant must, however, be decanted.
Retrofit		A refrigerant which can be used in equipment but will require modifications to the plant. This can vary between an oil change to compressor replacement.
Retrofill		This term is used to describe the action of replacing an existing refrigerant with an alternative. It therefore strictly applies to drop-ins and retrofits, but can also be applied loosely to add-ins.
Azeotrope		A mixture of refrigerants which behave thermodynamically as though they were a single fluid. It boils at a constant temperature.
NARM	(non-azeotropic refrigerant mixture)	A mixture of refrigerants whose composition in the liquid stage varies from its composition in the vapour stage during condensation and evaporation. Importantly, phase change occurs over a temperature range referred to as the glide and not at a fixed boiling point.
NARB	(non-azeotropic refrigerant blend)	An alternative term meaning the same as NARM.
ODP	(ozone depletion potential)	The ability of a refrigerant to destroy stratospheric ozone relative to R11 which is defined to have ODP=1.
GWP	(global warming potential)	A measure of a refrigerants ability to contribute to global warming relative to carbon dioxide which is defined to have GWP=1.
HGWP	(halon global warming potential)	An alternative measure to the GWP, taking R11 as the datum rather than carbon dioxide. It results in significantly lower values for alternative refrigerants i.e. HFC134a: GWP=420, HGWP=0.28 (over 500 yrs).
TEWI	(total equivalent warming impact)	The TEWI is a measure of a system’s contribution to global warming. It takes account of the refrigerant GWP and the carbon dioxide generated as a result of power consumption. The carbon dioxide emissions are often the most significant contributor to global warming.
AFEAS	(alternative fluorocarbon environmental acceptability study)	A study to determine the environmental impact of alternative refrigerants
AREP	(alternative refrigerant evaluation programme)	A study to determine the performance of alternative refrigerants
COP	(coefficient of performance)	A measure of efficiency. Equal to cooling duty of plant divided by power consumption.
SCD	(specific compressor displacement)	A measure of the volume of refrigerant which a compressor must displace to achieve a unit of cooling.