Industrial refrigeration
(including ice rinks)

Significant energy savings can be achieved by simple measures such as paying attention to the commissioning and control of refrigeration system. Examining the energy efficiency opportunities while approaching CFC/HCFC phase-out could transform essential change into profitable action.

This guidance note has two primary purposes:

- The identification of 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 observation has 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accelerating these phase-out schedules and as recent history shows, all revisions to the Montreal Protocol have been superseded by more stringent time scales.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.

Industrial refrigeration includes refrigeration for ice manufacturing, ice rinks and chemicals manufacturing. Ice manufacture and the cooling of ice rinks is dominated by ammonia (R717) and R22, with R12 and R502 also being used. Chemical manufacturers often make use of the process chemicals as refrigerants although ammonia is the most common choice in the industry. Many other refrigerants including CFCs, HCFCs and hydrocarbons are also used as primary and secondary refrigerants during chemical manufacture. Due to the diversity of the sector this information sheet addresses the areas above but concentrates on ice rinks.

Ammonia is not covered by current legislation which will phase-out R12 by 1996 (Table 1) and R22 over a longer time-scale (Table 2). The imminence of the phase-out time scales makes it imperative that managers address the issue now and create a coherent strategy for dealing with new and existing plant. Although the time-scale for the phase-out of HCFCs is not as pressing a contingency plan should be created as insurance against the acceleration of current schedules.

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 presents an ideal opportunity to implement energy efficiency measures. A high proportion of the energy wastage in industrial process arises from incorrect operation of equipment and poor commissioning of controls so significant savings can be achieved for little to no cost. Research shows that heat loads on ice rinks can be reduced by around 64% simply by paying attention to design and operation.

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 temperature lifts in refrigerating plant
- Optimise compressor and system operation
- Institute planned maintenance

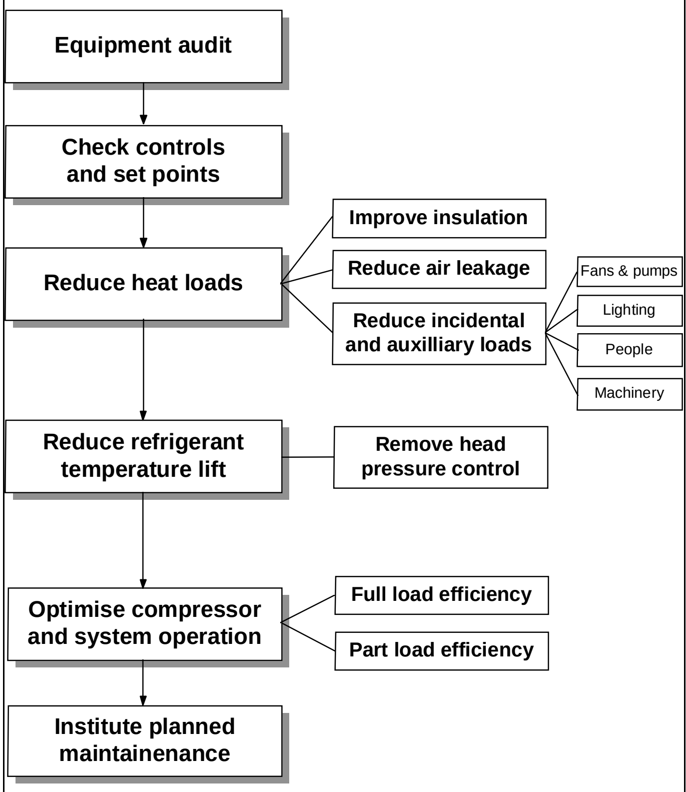
Audit existing equipment

The equipment audit is dealt with in detail in a later section (Managing CFC/HCFC phase-out). In brief, it involves identifying all refrigerating 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.

Check controls and set points

Ensuring that controls are correctly commissioned is a relatively cheap and easy activity which can lead to large energy savings. Narrow temperature control bands can result in equipment operating more frequently than necessary and leads to cycling which can reduce efficiency. Adjusting the time constants of the control algorithm can easily remedy this. All thermostat and humidistat set points should be checked.

Figure 1: Optimising energy efficiency



Reduce heat loads

Any reduction in heat loads results in a reduction in required refrigeration capacity and therefore energy consumption. The types of heat loads will vary significantly between industrial processes and, ice rinks apart, can be quite small. For chemical manufacture and ice production heat loads will be via conduction and radiation between the plant and the ambient environment.

In industrial plants the use of process integration techniques can identify the potential for direct heat exchange as well as optimisation of the cooling levels provided.

For ice rinks, particularly indoor rinks, heat loads will be similar to more typical refrigeration applications such as cold stores. The main ways of reducing heat gains to ice rinks are by focusing on:

- Insulation improvements
- Air leakage
- Incidental and auxiliary gains

- Insulation improvements

The walls of an indoor rink should be well maintained to guard against damage or degradation of the insulating material. Visual inspection will give first indications of problems while thermographic inspection will show up cold areas where insulation is poor. Heat gain from the ground below the rink and at the edges is typically 2-4% of the total heat load. However, it is unlikely that the floor insulation standards would be increased after the building of the rink as the floor beneath the ice is typically of concrete construction. The greatest source of heat gain to the ice is via radiative heat transfer between the ice and the roof, accounting for 28% of the total loading. The installation of a low emissivity ceiling and proper operation of the rink (i.e. temperature control) can reduce the loading by up to 90% and will also reduce condensation problems.

- Air leakage

Ventilation rates should be kept to the minimum acceptable level to reduce the latent load. However, air can leak through poorly sealed walls or through access doors. Sealing joins in the building fabric will reduce infiltration to the building which will impact on the sensible refrigeration load and the latent load, as humidity must be controlled to prevent misting.

- Incidental and auxiliary heat gains

Pumps, ground heat, ice resurfacing, lighting radiation and skaters all add to the load on the refrigeration system. Up to 60% of the kilowatt rating of ceiling mounted lighting is transferred via radiation directly to the ice. The lighting energy and that of other auxiliary equipment is thus paid for twice - first the direct power cost and then the refrigeration cost of removing the heat from the refrigerated space. The selection of efficient auxiliary equipment and the avoidance of its unnecessary use is therefore doubly important.

High efficiency lighting such as high frequency fluorescents should be used as a matter of course in indoor rinks and controls should be fitted to ensure that they are only in use when necessary. Heat gains from coolant circulating pumps, which can account for up to 12% of refrigeration load, can be reduced by ensuring that the pump and motor operate under a regime of maximum efficiency. This can be achieved by pump cycling, using two speed motors, multiple pumps or variable speed motors. Ice resurfacing also poses a significant heat gain on the system and the maintenance of good water quality will allow a lower water temperature and volume to be used, reducing the required capacity of the rink refrigeration system.

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.

In systems using a thermostatic expansion valve 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.

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. Capacity control methods will be optimised by the use of electronic expansion valves which have 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 2.

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.)

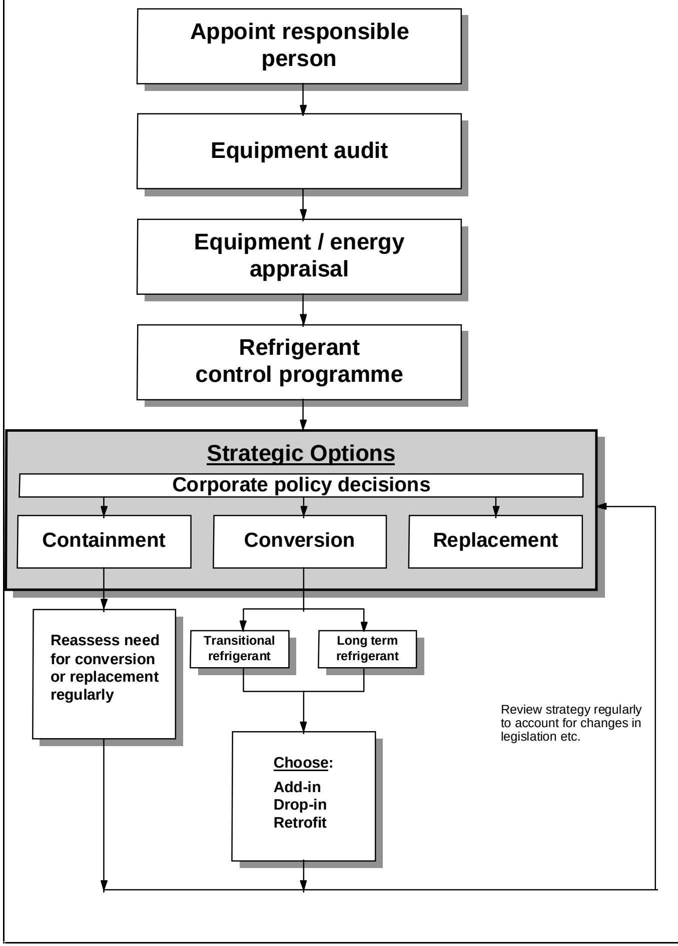
Appraise equipment

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, switching to 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 2: 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.

The predominant refrigerants used for industrial refrigeration are ammonia (R717), R22 and R12 with a wide variety of others being used in industrial processes depending on the process in question as the process chemicals often double as refrigerants. Due to the diverse nature of industrial refrigeration systems this section will concentrate on the conversion of ice rinks only. Ice rink refrigeration is dominated by ammonia and R22 systems with R12 and R502 systems also in existence. Conversion from ammonia is unnecessary as it is not ozone depleting. This section will therefore consider how to approach the conversion of R22 ice rinks. Figure 4 lists the performance data of many R22 alternatives at evaporating temperatures of -5°C[1]. These tables are ***not*** exhaustive, but do list most of the alternatives currently manufactured by the major refrigerant producers.

The tables give the actual performance details of R22 and its alternatives, while their COPs and SCDs (both shaded) are shown ***relative*** to R22. **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 can vary significantly from that of R502.**

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 while a long term drop-in becomes available.

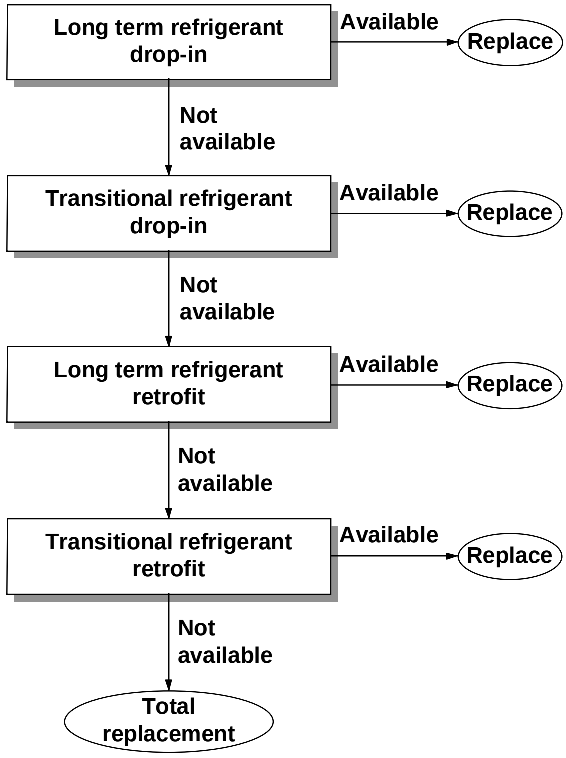
   This gives the following priority:

   - 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 3: Choosing an alternative refrigerant



Applying the logic of Figure 3 to the table of R22 alternatives in Figure 4:

Long term drop-in R22 replacements:

There are currently no alternatives available in this category.

Transitional drop-in R22 replacements:

There are no drop-in R22 replacements shown in Figure 4. However, G2018b is a drop in but is not included in the table due to the absence of technical information at the time of writing.

Long term retrofit R22 replacements:

- Klea 66/AC9000
- AZ-20
- R134a

Klea 66/AC9000 and AZ-20 are the only refrigerants in Figure 4 marketed as true R22 alternatives in this category and are apparently a good match for R22 thermodynamic properties. Although R134a can be used as an R22 replacement it will result in significantly reduced chilling capacities.

Transitional retrofit R22 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. Even when conversion 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. The use of ammonia plant can also be re-evaluated.

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: (0905) 602 4700) and the HEVAC Association in the UK (Tel: (016285) 31186).

Figure 5b: Performance of R22 alternatives*

Refrigerant	**R22**	**AZ-20**	**R717**	**R134a**	**Klea 66 AC9000**
ASHRAE No.	R22	R410A	R717	R134a	R407C
Manufacturer	many	AS	many	many	ICI/DP
Status	Transition	Long term	Long term	Long term	Long term
Drop-in		No	No	No	No
Retrofit		Yes	No	Yes	Yes
Available		Yes	Yes	Yes	Yes
	Tev (°C)				
	-5	**-5**	**-5**	**-5**	**-5**
SCD (dm^3/kJ)	0.35	0.67	0.93	1.63	1.03
COP	3.45	0.93	1.01	1.00	0.80
Pev (bar a)	4.21	6.78	3.55	2.43	4.21
Pco (bar a)	15.3	24.1	15.6	10.1	16.5
Tdis (°C)	82.8	81.0	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 R22 at the same evaporating temperature.
∴ To find the COP of R134a at Tev= -5°C, COP= 3.45*1.00 = 3.45

Legend

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

Case study - Refrigerant retrofit

A centrifugal compressor, used in a chlorine liquefaction process has been successfully converted from R12 to R134a. The retrofit was carried out in six main steps:

- Installation evaluation. 4 days
- Purging and flushing of existing mineral oil. 1 week
- Replacement of compressor shaft seal. 1 day
- Recovering R12 / introduction of R134a. 2 days
- Validation of R134a performance. 5 days

The approach to flushing the mineral oil was slightly different to that followed in typical refrigeration applications. The traditional flushing technique was adopted to remove mineral oil from the compressor. That is, replacing mineral oil with POE oil, running the compressor and then replacing the POE oil. This procedure is continued until the concentration of mineral oil within the POE oil falls below a certain level.

An additional procedure was also followed to ensure the evaporator was properly cleaned:

- Mineral oil was mechanically drained from the evaporator.
- The evaporators were flushed with R12 to remove any additional pollutants. A closed loop was used to prevent loss of the R12.

The system was then charged with R134a.

The installation has now run successfully for more than one year.

Case study - Energy efficiency

A Finnish manufacturer of flexible packaging saved 37% of their annual energy consumption by purchasing a separate cooling system and production machine, rather than an integrated one. The production process requires heat to melt plastic granules but also needs a large amount of cooling water at 10°C. By specifying separate production and cooling machines the cooling system could be designed to provide free cooling when the ambient temperature was below 19°C. The cooling for the production process is obtained from a combination of dry air coolers and standard refrigeration equipment. When the ambient air temperature falls below 4°C then the air coolers can provide enough free cooling to meet the process needs. It is estimated that this installation had a payback of 2.5 years.

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.