Chilled Storage Refrigeration

Energy savings of over 50% are achievable in many chilled storage refrigeration systems. Examining the energy efficiency opportunities while approaching CFC/HCFC phase-out could transform essential change from an 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accelerating these phase-out schedules and as recent history shows, all revisions to the Montreal Protocol have been superseded by more stringent time scales.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.

Chilled storage refrigeration is dominated by the use of R12, but R22, R502 and ammonia are also in common use. 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. Ammonia plant is not covered by present legislation, but remains an option when equipment replacement is being considered.

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 chilled storage refrigeration 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. Narrow temperature control bands 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. Overcooling by 1°C will lead to an increase in energy consumption of over 2%.

Reduce heat loads

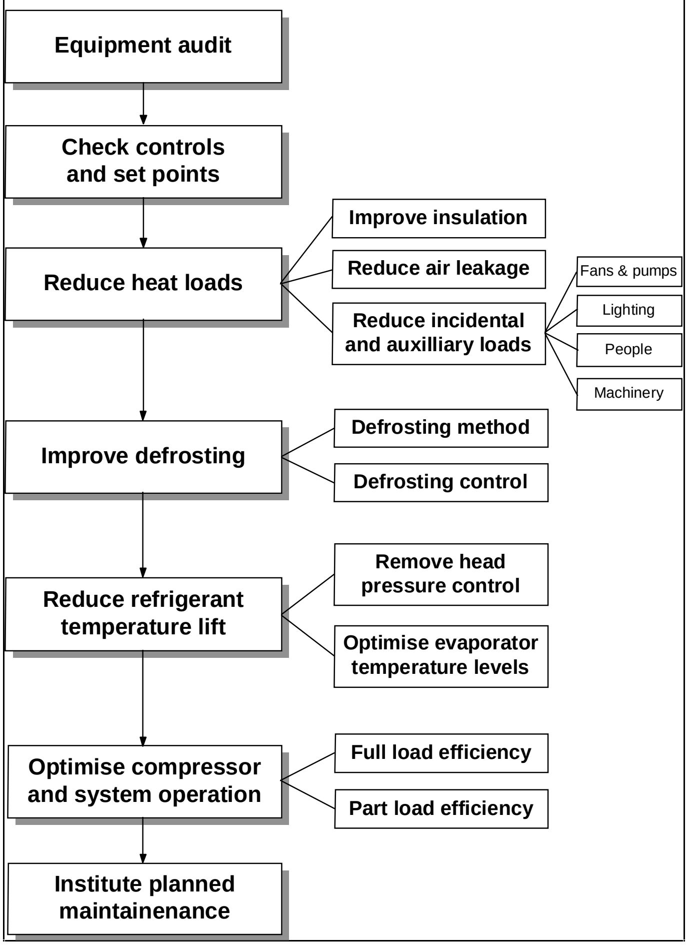
Any reduction in heat loads results in a reduction in required refrigeration capacity and therefore energy consumption. There are three main methods for reducing heat loads:

- Improving insulation.
- Reducing air leakage.
- Reducing incidental and auxiliary gains.

- Insulation improvements

The walls of a refrigerated space 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.

Figure 1: Optimising energy efficiency



- Air leakage

Air can leak through the degraded fabric of an enclosure or through an access such as a door. Taking the steps outlined above should prevent fabric leakage. Reducing air leakage through doors is outlined below:

Access is required to all cold stores for loading and unloading causing unavoidable air ingress. However, this ingress can be limited by a number of options, although the regularity of access will influence the decision. A tight fitting door must be used during periods where access is not required, but when access is required on a regular basis strip curtains or automatic doors can be used to limit the ingress. However, secondary sealing systems can encourage users to neglect the use of the main door. An automatic door can reduce the cooling load by 100MWh per annum in comparison with strip curtains (2.4m x 2.1m doorway, 4.5 hours use per day, storage temperature of 3°C and external temperature of 15°C). The use of two entrances to a single store should be avoided where possible as it encourages air movement through the chilled space. If appropriate, airlocks should be considered.

- Incidental and auxiliary heat gains

Evaporator fans, air circulation fans, lights and machinery in the store increase the load on the refrigeration system; the power for these items 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 fans should be installed where possible. As the peak loads occur in cold stores during and after loading, two-speed fans can result in significant savings. They can operate at a setback condition during periods of lower cooling demand (e.g. overnight).

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 store is not over illuminated; levels of 150 to 300 lux are generally satisfactory. Non-uniform illumination may be acceptable, with higher levels being used near machinery and lower levels in passageways. A simple way of achieving this is to remove some of the lamps, but checks should be made to ensure that this will not adversely affect the controllers and the ballasts and that a safe and acceptable level of illumination will be maintained. In spaces which are intermittently occupied 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. Personnel detectors can also be used.

Improve defrosting

Defrosting is required to remove the frost which forms on an evaporator when the refrigerant boils within it at below 0°C. In chilled stores the air temperature is usually warmer than this and defrosting can often be eliminated if the evaporator is increased in size until the evaporating temperature lies above 0°C. If this is not practical then using the air in the store to melt the frost is a more efficient method of defrosting than using hot refrigerant vapour from the compressor or using electric heating elements. As defrosting by this method is slower than other methods the refrigeration capacity may have to be slightly larger.

Proper control of defrosting is essential for an energy efficient system. The defrost cycle should only be initiated when a layer of frost has developed and should stop immediately the frost has been removed. A time clock method is satisfactory if the rate of frost formation is fairly constant, otherwise automatic methods of frost detection, directly detecting frost formation or noting the fall in air velocity should be used. Defrost completion can be detected by measuring the coil fin temperature or the refrigerant pressure in the evaporator.

Reduce temperature lifts

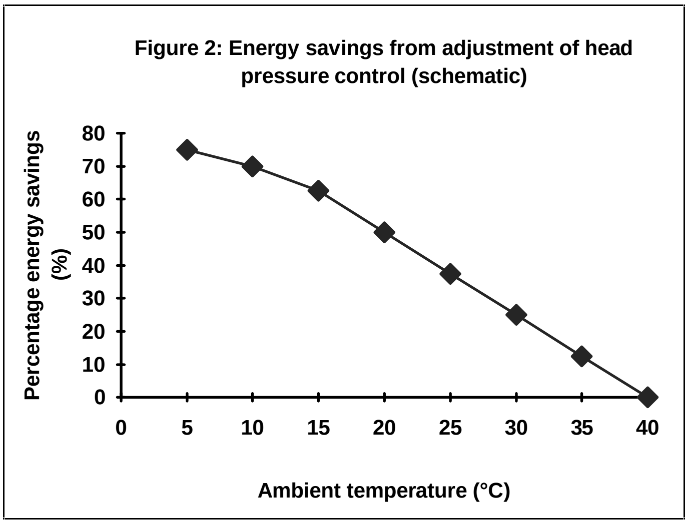
The efficiency of refrigerating plant is dependent upon the size of the temperature lift between the evaporator and the condenser: the smaller the lift the more efficient the system.

- 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).



- Optimising evaporator temperature levels

When more than one chilled space is being cooled by the same compressor set then energy will be wasted if they are not operating at the same evaporating temperatures. If the chilled room temperatures differ by more than 10°C then the use of separate compressor sets should be considered for each of the different temperature levels.

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.)

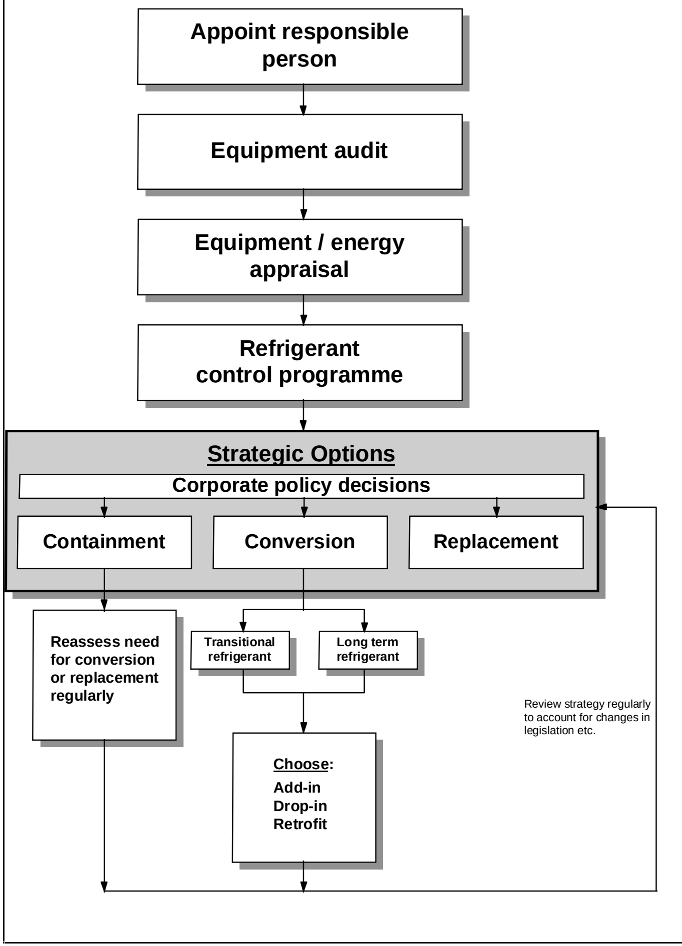
Appraise equipment

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.

Chilled storage refrigeration is dominated by R12 equipment, with R22 and R502 equipment in use in some applications (ammonia equipment is ignored here). Conversion from R12, the primary refrigerant, is considered in this guidance note. Figure 5 lists the performance data of many R12 alternatives at evaporating temperatures of -5°C and +5°C respectively[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 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.

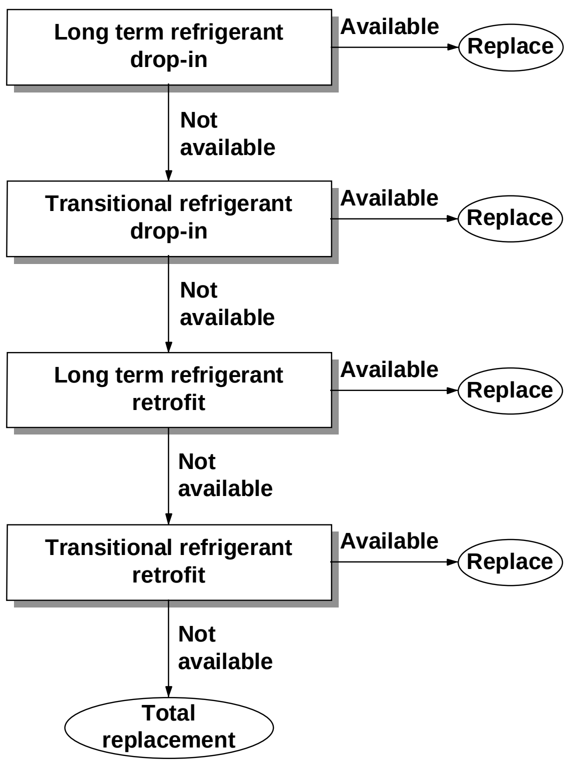
   This gives the following priority:

   - 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 5 gives the following results:

Long term drop-in replacements:

There are no refirgerants available in this category

Transitional drop-in replacements:

- FX56
- FX57
- G2015
- MP39
- MP66

The list above shows a selection of 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 of centrifugal plant in particular can be very expensive and 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.

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 5: 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**	**+5**	**-5**	**+5**	**-5**	**+5**	**-5**	**+5**
SCD (dm^3/kJ)	0.56	0.40	1.01	0.97	0.86	0.85	0.81	0.80	0.88	0.86	0.83	0.82	0.83	0.81
COP	3.52	4.88	0.98	0.99	0.99	0.94	0.99	0.99	0.98	1.00	0.98	0.98	0.94	0.95
Pev (bar a)	2.61	3.62	2.43	3.49	2.88	4.06	3.07	4.23	2.78	3.99	2.98	4.22	3.27	4.62
Pco (bar a)	9.60	9.60	10.1	10.1	11.3	11.3	12.0	12.0	11.2	11.1	11.8	11.8	12.7	12.7
Tdis (°C)	65.0	59.6	61.9	57.2	76.4	71.2	78.4	70.3	79.4	71.0	79.8	71.5	64.4	59.9

*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= 0.95*4.88 = 4.64

Legend

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

Case study - Refrigerant retrofit

Changing from R12 to R134a in a chocolate store

Refrigeration equipment at a chilled store used for holding chocolate confectionery prior to wrapping was recently retrofitted with R134a, the most common of all R12 replacements. The system initially comprised two R12 chillers with duties of 17.8 kW and 39 kW, each having identical primary refrigeration circuits but with a common secondary refrigeration circuit. Chilling of the glycol secondary refrigerant was achieved via two identical and independent refrigeration circuits. The glycol was pumped through the two evaporators and then fed to two air cooled coils in the cold store. The design evaporating temperature was -3.9°C with the outlet glycol temperature being 1.7°C. Glycol temperature was varied by compressor cylinder off-loading. Each chiller had an eight cylinder direct driven compressor with a 15kW drive motor running at 1450rpm. At that time, only the larger of the two chillers were converted from R12 to R134a. However, prior to the conversion all of the system parameters such as power consumptions, temperatures, pressures and flow rates were measured to allow a direct comparison between before and after performance.

The mineral oil was removed from the compressor crankcase and oil filter and replaced with an ester oil with a matching viscosity. The plant was then run for four hours and the ester oil contaminated with mineral oil residues was drained. The crankcase and oil separator were then refilled with fresh ester oil. The procedure was repeated until the mineral oil concentration was less than 1%. The second stage of the procedure involved removal of the R12 to a recovery cylinder prior to recycling. Minor system modifications were then necessary. This involved changing the expansion valves and filter/drier core to appropriate types. The system was then leak tested. The system was then evacuated using the triple evacuation method to ensure all traces of R12 and other contaminants were removed. This involved repeated evacuation to a a pressure of 1mm Hg or lower. The system was then charged with R134a.

The performance prior to and following the retrofit are shown in the table below. There was a slight increase in refrigeration duty (~1%) which was accompanied by a 12% rise in COP.

Comparison of performance before and after retrofit

	Duty (kW)	Power (kW)	COP
R12	27.8	11.1	2.50
R134a	28.2	10.1	2.79

Case study - Energy efficiency

To test the use of lower fan speeds in controlled atmosphere chilled stores for apples, three of the thirty nine new cold stores built at Geldermalsen Auction in the Netherlands had variable speed fans installed in a false ceiling rather than fixed speed fans installed over the door in a design incorporating a sloping roof.

The better air distribution provided by the false ceiling allowed the required air circulation rate to be halved from 50 times the volume of the store circulated per hour down to 25 during initial refrigeration and from 25 to 12.5 during the storage period.

The energy used by the fans was cut by 30%, this corresponds to a fan energy saving of 2.2 kWh/kg of fruit stored over a season. If the savings in refrigeration load are also taken into account the savings will be around 3 kWh/kg of fruit stored.

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.