AIRAH wishes to acknowledge the assistance provided by **Environment Australia** in producing this booklet.

ISBN 0-949436-41-0

First Edition:	August 1994
Second Edition:	May 1995
Third Edition:	June 1996
Fourth Edition:	November 1997
Fifth Edition:	April 1998
Sixth Edition:	June 1998
Seventh Edition:	January 2003

DISCLAIMER

The Information or advice contained in this document is intended for use only by persons who have adequate technical training in the field appropriate to the contents of this document. This document has been compiled as an aid only and the information or advice should be verified before any person puts it to any use. The user should also establish the applicability of the information or advice in relation to any specific circumstances. While the information or advice is believed to be correct, both the Australian Institute of Refrigeration, Air Conditioning and Heating Inc. and Environment Australia, its officers, employees and agents disclaim responsibility for any inaccuracies contained within the document including those due to any negligence in the preparation and publication of the said document.

AIR CONDITIONING AND REFRIGERATION INDUSTRY REFRIGERANT SELECTION GUIDE - 2003

Compiled and written by:

C.A. LOMMERS, Dip.Mech.Eng., F.AIRAH, M.ASHRAE

Published in Australia by:

The Australian Institute of Refrigeration Air conditioning and Heating Inc (AIRAH)

Level 7, 1 Elizabeth Street • Melbourne • VIC • 3000

www.airah.org.au

Tel: (03) 9614 8868 • Fax: (03) 9614 8949

TABLE OF CONTENTS

PART 1: OVERVIEW OF ISSUES

1.1 Introduction

This guide includes information for designers and contractors in the refrigeration and air conditioning industry that assists in judgements on environmental issues and the effect refrigerants and systems can have on the environment. This document briefly explains the differences between ozone depletion and global warming and the impact these two distinctly different processes have on the environment.

The Australian Government is a signatory to the *Montreal Protocol on Substances that Deplete the Ozone Layer (the Montreal Protocol)* which sets out a mandatory timetable for the phase out of ozone depleting substances (ODS) and urges additional action to minimise damage to the ozone layer. This guide includes current requirements of the *Montreal Protocol*, the Commonwealth *Ozone Protection Act 1989* and the various State/Territory requirements as indicated in the "Revised Strategy for Ozone Protection in Australia 1994".

This document covers CFC (chlorofluorocarbon), HCFC (hydrochlorofluorocarbon), HFC (hydrofluorocarbon) and natural refrigerants and their allocated ASHRAE or ISO numbers. Further alternatives may be included when testing and safety requirements have been addressed in the applicable Australian Standards and Codes. This guide provides a better understanding of alternative refrigerants and system performance effects resulting from the use of refrigerants that have little or no effect on the ozone layer and a minimal impact on global warming.

1.2 What is Ozone Depletion?

Ozone is an extremely rare gas in the atmosphere, representing just three out of every 10 million molecules; however, it is essential to life on earth as we know it. Ninety percent of ozone exists in the stratosphere between 10 to 50 kilometres above the earth. The ozone layer absorbs most of the harmful ultraviolet-B radiation from the sun. It also completely screens out lethal UV-C radiation.

Depleting the ozone layer allows more harmful radiation to reach the earth, resulting in more melanoma and non-melanoma skin cancers, more eye cataracts, weakened immune systems, reduced plant yields, damage to ocean eco-systems and reduced fishing yields, adverse effects on animals and more damage to building materials and plastics.

Stratospheric ozone depletion results in a thinning of the ozone layer and the appearance of an ‘ozone hole’ at the Antarctic pole each Spring. The ozone layer over the Antarctic has steadily weakened since measurements started in the early 1980’s. The polar vortex makes Antarctic air appreciably colder, by about 5 – 10^{o}C, than the air above the Arctic. Polar stratospheric clouds which form during the Antarctic winter in the very cold stratosphere play a major role in creating the conditions for the loss of ozone. The low temperature (-78^{o}C) clouds comprise tiny particles of frozen water vapour, nitrogen and nitrogen oxides. The clouds act as reservoirs of chlorine held in inactive compounds such as hydrogen chloride, hydrochloric acid and chlorine nitrate, which do not react with ozone. With the coming of spring and the end of a long winter over the Antarctic, ultraviolet radiation from the sun encounters the stratospheric ice clouds and catalyses reactions on their surfaces, converting the inactive compounds to reactive chlorine monoxide. The chlorine monoxide destroys ozone at a very rapid rate – as much as 1% per day.

Similar reactions occur with bromine which is derived from halons and is responsible for between 10% and 30% of ozone loss. The key conditions are the extreme cold, the still air within the polar vortex, the reservoir of chlorine components in the polar clouds and the presence of ultraviolet radiation. The ozone hole and ozone depletion results from CFCs, HCFCs, Halons, methyl bromide and other ODS released to the atmosphere. The Ozone Depletion Potential (ODP) reflects the combination of percentage (by weight) of chlorine atoms and the lifetime of the compound in the atmosphere.

1.3 What is Global Warming?

The earth is surrounded by a thin film of gases which form the atmosphere. It is the composition of the atmosphere that distinguishes the earth from other planets in our solar system and creates the conditions necessary for the diversity of life on the earth's surface and in the oceans. Greenhouse gases have the potential to increase the earth's average temperature by trapping some of the heat that the earth normally radiates back into space. The greater the concentration of greenhouse gases in the atmosphere, the greater the potential for a warmer planet and changes to the earth's climate.

The composition of the atmosphere has changed over geological time. In the absence of human activity, such changes usually take place over thousands of years. However, human activities over the last two hundred years have measurably changed the composition of the atmosphere through the emission of greenhouse gases.

Since pre-industrial times, CO_2 concentration in the atmosphere has increased by about 28%, (31 to 32% according to the latest IPCC assessment reports) methane by 145% and nitrous oxide by 13%. These are the three main greenhouse gases. Fluorinated compounds such as HFCs, PFCs and SF_6 are also greenhouse gases. Although their atmospheric concentrations are small, they have a relatively long atmospheric life.

GWPs (Global Warming Potential) are used by, among others, policymakers to compare the impact on the climate system of emission of different greenhouse gases. The GWP index is relative to carbon dioxide (CO_2), which is normalised at 1. As greenhouse gases differ in their atmospheric lifetimes, GWPs also have a time component. Time horizons of 20 years and 100 years are used in this document to enable the proper evaluation on the environment.

1.4 An Accepted Method of Estimating the Impact of Global Warming

Methods of calculating the total effect on Global Warming have been developed using the direct (due to emission) and indirect (due to energy requirement) effects of refrigerants considered for use in a system.

The introduction of TEWI (Total Equivalent Warming Impact) enables designers and contractors to estimate the equivalent CO_2 emission to atmosphere from system leakage (direct emission) and energy consumption (indirect emission). The largest portion of the global warming effect of a system is normally attributed to the (indirect) CO_2 emission due to the required energy generation. Typically, the indirect effect is 90 to 98% of the global warming effect. Based on the high percentage of fossil fuels used in power stations the average European CO_2 release is around 0.6 kg per kWhr of electrical power generated. The methods of generating power vary from state to state and from country to country, as do their respective effects on Global Warming (egg. coal fire generation will release between 0.6 and 0.8 kg of CO_2 per kWhr of electrical energy generated, whereas hydro power generation will only contribute a negligible quantity of CO_2 to atmosphere). The source of the energy required for the operation of a system would therefore have a direct impact on global warming effect.

The criteria used to estimate the Total Equivalent Warming Impact can be summarised as follows:

$$\text{TEWI} = \text{direct} + \text{indirect emission}$$

OR

$$\text{TEWI} = \text{leakage} + \text{energy consumption}$$

OR

$$\text{TEWI} = (\text{GWP} \times L_{\text{annual}} \times n) + (E_{\text{annual}} \times ß \times n)$$

Where:

GWP = Global Warming Potential of Refrigerant, relative to CO_2 (GWP CO_2 = 1.0)
L_{annual} = Leakage rate (kg) per annum
n = number of years
E_{annual} = Energy consumption (kWhr p.a.)
ß = CO_2 emissions per kWhr
TEWI = CO_2 (kg)

Refrigeration and air conditioning systems account for 10 to 20% of total electricity consumption in developed countries. Research on TEWI (Total Equivalent Warming Impact) has shown that for most applications the impact on global warming will be greater from energy consumption than from CO_2 equivalent emission (release) of refrigerants. Current and future technological advances for improving the energy efficiency of refrigerating and air conditioning systems will play a decisive role in reducing the greenhouse effect.

Example:

Consider a refrigeration system for a typical liquor store cool-room installation comprising a roof mounted air cooled condensing unit and two evaporators. The refrigerant selected for the system is R507 and it contains 50 kg by volume.

Electricity consuming components include a 6.2 kW compressor motor; a 0.3 kW condenser fan motor and two 0.15 kW evaporator fan motors.

The average annual refrigerant leakage has been estimated at 10% of the total system volume.

Direct Global Warming Impact, calculated for a 20 year time horizon:

Refrigerant GWP:	5,700 kg CO_2 per kg R507
Estimated annual refrigerant loss:	10% of 50 kg = 5 kg
Estimated Direct Global Warming Impact for 20 year period:	5,700 x 5 x 20 = 570,000 kg CO_2

Indirect Global Warming Impact, also calculated for a 20 year period:

Estimated Compressor plus Condenser fan motor daily operating hours at 50% of 16 hour daily calculated operating hours is 8 hours per day.

Estimated daily operating hours for evaporator fans is 24.

Daily energy consumption:

Compressor and condenser fan motors:		(6.2 kW + 0.3 kW) x 8 hours
	=	52 kW daily
Evaporator fans:		0.3 kW x 24 hours
	=	7.2 kW daily
Total daily consumption:	=	59.2 kW
Annual energy consumption:		59.2 kW daily x 365 days per annum
	=	21,608 kW per annum
Estimated CO_2 emission per kWhr generated:		0.7
Estimated Indirect Global Warming Impact:		21,608 x 0.7 x 20
	=	302,512 kg CO_2

TEWI = leakage + energy consumption

TEWI = 570,000 + 302,512 = 872,512 kg CO_2

PART 2: NATIONAL AND INTERNATIONAL CODES

2.1 Montreal Protocol

The timetable set by the *Montreal Protocol on Substances that Deplete the Ozone Layer* is for production and consumption of ODS in developed and developing countries. Consumption is defined as the quantities manufactured and imported less those quantities exported or destroyed in a given year. Percentage reductions relate to the base year production for the substance. The following table summarises the requirements laid down under the 1987 *Montreal Protocol*, the 1990 London Amendment to the Protocol, the 1992 Copenhagen Amendment to the Protocol, to phase out consumption of those CFC and HCFC refrigerants commonly used in the air conditioning and refrigeration industry in Australia.

Ozone Depleting Substance	Developed Countries	Developing Countries
Chlorofluorocarbons (CFCs)	Phased out end of 1995 [a]	Total phase out by 2010
Halons	Phased out end of 1993	Total phase out by 2010
Carbon Tetrachloride	Phased out end of 1995 [a]	Total phase out by 2010
Methyl Chloroform	Phased out end of 1995 [a]	Total phase out by 2015
Hydrochlorofluorocarbons (HCFCs)	Freeze from beginning of 1996 [b] 35% reduction by 2004 65% reduction by 2010 90% reduction by 2015 Total phase-out by 2020 [c]	Freeze in 2016 at 2015 base level Total phase out by 2040
Hydrobromofluorocarbons (HBFCs)	Phased out end of 1995	Phased out end of 1995
Methyl Bromide	Freeze in 1995, at 1991 base level [d] 25% reduction by 1999 50% reduction by 2001 70% reduction by 2003 Total phase out by 2005	Freeze in 2002 at average 1995-1998 base level 20% reduction by 2005 e Total phase out by 2015

NOTES:

a With the exception of a very small number of internationally agreed essential uses that are considered critical to human health and/or laboratory and analytical procedures.

b Based on 1989 HCFC consumption with an extra allowance (ozone depleting potential (ODP) weighted) equal to 2.8% of 1989 CFC consumption.

c In addition, up to 0.5% of base level consumption can be used until 2030 for servicing existing equipment.

d All reductions include an exemption for pre-shipment and quarantine uses

e Review in 2003 to decide on interim further reductions beyond 2005.

CFC's: Production and imports of CFC refrigerants ceased on 1 January 1996, except where an essential use license is granted.

HCFC's: The Australian Government introduced controls on the import and manufacture of HCFC refrigerants from 1 January 1996.

Supply controls have been set at levels approximately half the amount allowable under the Montreal Protocol, but have been estimated by industry to be adequate to meet the demand in Australia.

The allowable import of HCFC refrigerants peaked in 1998-1999 and is subject to a phase out quota system. Substantive supply (imports) will cease by 2020 with only very limited supplies then available until 2030 to service remaining HCFC-dependent equipment, in accordance with the *Montreal Protocol* and the *Ozone Protection Act 1989*. The Commonwealth's environment agency, Environment Australia, is currently exploring proposals to extend Commonwealth regulation to include controls on end use. The sale of ODS and HFC/PFC refrigerants is likely to be restricted to registered persons under a national scheme.

2.2 How will this Phase Out affect Chlorine Based Refrigeration Systems?

If a system operates on Chlorine based refrigerants, including HCFC refrigerants, it may not be possible to purchase replacement Chlorine based refrigerants to re-charge/refill systems with refrigerant leaks. This would result in a deficient or inoperative refrigeration or air conditioning system.

The following table summarises the HCFC quota system that will limit HCFCs availability to industry:

Calendar Year:	Limit quantity of HCFCs available to industry
2002 and 2003	190 ODP tonnes per year
2004 and 2005	160 ODP tonnes per year
2006 and 2007	130 ODP tonnes per year
2008 and 2009	100 ODP tonnes per year
2010 and 2011	70 ODP tonnes per year
2012 and 2013	40 ODP tonnes per year
2014 and 2015	10 ODP tonnes per year
2016 to 2029	2.5 ODP tonnes per year
2030	Nil

ODP tonnes are calculated by multiplying the mass of the ODS, in tonnes, by its ozone depleting potential.

2.3 The United Nations Framework Convention on Climate Change

In response to growing international awareness of the potential problems of climate change, the United Nations General Assembly convened discussions from 1990 to 1992 to draft the *United Nations Framework Convention on Climate Change* (the Convention). Australia played an active role in these negotiations and, in December 1992, became one of the first countries to ratify the Convention. Parties to the Convention have agreed to work towards achieving the Convention's ultimate aim of stabilising 'greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system'.

In 1998, Australia's Government launched the National Greenhouse Strategy, outlining a comprehensive approach to tackling greenhouse issues. Measure 7.2 of the National Greenhouse Strategy committed governments to work with industry to develop environmental management strategies for the synthetic greenhouse gases – hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6). As explained under Part 1.4 of these guidelines, the comparatively high GWP of synthetic greenhouse gases (SGG) makes the correct handling of refrigerants that contain synthetic gases a significant contribution towards reducing Australia's total greenhouse gas emissions.

2.4 Proposed Commonwealth Approach and Future Legislation

The Commonwealth's primary regulatory mechanism is the *Ozone Protection Act 1989*. Following a substantial review of this legislation, the Commonwealth is now considering the extension of this Act to include SGG (primarily HFCs & PFCs) used in the air-conditioning and refrigeration industry and end use controls traditionally regulated by the State and Territory governments.

Proposed changes to the *Ozone Protection Act 1989* would include four new elements:

1. Supply controls for SGG;
2. End-use regulation;
3. Product stewardship requirements; and
4. Industry transition.

Supply controls for SGG would comprise controlled substance licenses for importers, exporters and manufacturers. License holders would be required to report on volumes of HFCs and PFCs imported, exported and manufactured. Further sales of HFCs and PFCs would be restricted to those who hold accreditation or certification under the amended legislation.

The Commonwealth would replace existing **End-Use Regulation** with a single national framework for the management of ODS and the SGG used as their alternatives. The same regulations and requirements would apply regardless of where you operate. The Commonwealth approach is expected to include a strong industry focus on flexibility and co-regulation. It is envisaged that, where appropriate, Industry based boards would administer training, certification and accreditation requirements under the proposed arrangement. The Commonwealth plan would include opportunities to incorporate existing industry codes and standards, giving legal backing to industry based initiatives.

Product Stewardship would establish clearly defined environmental responsibilities for the importers of pre-charged air conditioning equipment. The Commonwealth would support and help enhance voluntary measures already in place for bulk imports of HCFCs under the industry-based scheme Refrigerant Reclaim Australia. While they would not be compelled to sign up with the Refrigerant Reclaim Australia service, importers of pre-charged equipment would be required to demonstrate that they have appropriate arrangements in place to manage refrigerants at the end of their serviceable life.

The existing legislation includes a managed trust account – the Ozone Protection Reserve – that is used to fund projects that will assist in the phase-out of HCFCs and Methyl Bromide. The function of the Reserve would be changed to broaden its scope, assist **Industry Transition** and include the funding of HFC/PFC emission minimisation initiatives. The Reserve will look more closely at issues of emissions reduction strategies across all fluorocarbon refrigerants, as well as compliance with emission reduction requirements.

PART 3: DEALING WITH OZONE DEPLETION

3.1 Introduction

Designers and contractors should offer the following advice to their clients:

- The phase out of CFCs and the HCFC quota system has reached the stage where good management of existing chlorinated refrigerants is vital in the successful transition to non-chlorinated refrigerants.

- Systems using chlorinated refrigerants must be identified. All refrigeration and air conditioning systems must have labels showing the type of refrigerant and lubricant used.

  If refrigerants or lubricants cannot be identified, contact the equipment manufacturer or a qualified refrigeration engineer to identify the refrigerant and/or lubricant used in the system.

  If chlorinated refrigerants are used, act now by planning containment and/or replacement of the ODS. **REFRIGERANT LEAKAGE MUST BE MINIMISED NOW.**

- Determine the importance of the affected refrigeration system by assessing the nature and dependence of the system to the facility. For example, *if a plant failure could halt production or sales, phase out plans should take a very high priority.* Conversely, if a system consists of a small air conditioning plant in an office, and the facility owner feels that he can afford to be without it for a while, a technician or refrigeration engineer can respond on a crisis management basis.

It is therefore necessary to determine how crucial the refrigeration/air conditioning plant is to the facility.

Examples:

Small self contained units (i.e. domestic refrigerators, small retail display cases, small air conditioners) - Refrigeration systems of this type are very reliable and often run for 20 years without maintenance. In these circumstances your actions should be to:

Continue running the existing plant until it reaches the end of its useful life.

Make the appropriate contingency plans in case the system breaks down and loses its charge of refrigerant.

Plan how to safely dispose of an old system without venting refrigerant to atmosphere.

Small, medium and large systems use more complex items of refrigeration equipment and usually require some on site system assembly and refrigerant filling. *Refrigeration systems in this category are susceptible to refrigerant leakage and often require regular maintenance.* Typical examples are coolrooms, freezer rooms, split system air conditioners, chilled water systems, and built up direct expansion plant. There is a wide range of technical solutions that can be applied. In some cases the correct line of action is quite clear, but in most instances there are options that require further assessment.

The following step by step approach will ensure that all relevant options are properly assessed.

3.2 Step 1: Equipment Identification

Before assessing the available technical options it is important to know the type of equipment and refrigerant that is used in EACH plant or system, as this will have direct impact on the choices available.

REFRIGERANT AND LUBRICANT:	Identify the type of refrigerant and lubricant being used.
COMPRESSOR TYPE:	The type of compressor used in a refrigeration system has a strong influence on conversion opportunities (e.g. hermetic, semi-hermetic and open drive compressors have varying opportunities and limitations for conversion).
SYSTEM OPERATING PRESSURES:	The operating pressures of refrigerants will limit the alternatives and types of replacement refrigerants available for the existing system.
AGE OF PLANT:	The age and life expectancy of the plant will influence the decision to convert existing equipment or replace it with a new plant.
COMPATIBILITY:	Various materials used in CFC and HCFC refrigeration systems can affect conversion options. When considering conversion to a different refrigerant, establish the type of lubricant, elastomers (rubber/plastic seals, gaskets etc.) and metals used. New refrigerants must be chemically compatible with all materials used in the existing system.
COOLING CAPACITY:	Determine the required cooling capacity for each facility/system and the shortfall/surplus capacity installed on the site. This may affect the technical options to be adopted. System conversions can accommodate system shortfalls and/or optimise on total energy input by utilising current technologies, design and installation techniques.

3.3 Step 2 - Refrigerant Usage Audit

AVAILABLE CFC BANK:

Determine the total quantity of each chlorinated refrigerant being stored on site in existing systems and equipment. This will provide important data on the need for replacement and the potential to re-use chlorinated refrigerant from converted or replaced plants and systems.

ANNUAL REFRIGERANT USAGE:

Many plants suffer from a considerable degree of refrigerant leakage. A low refrigerant consumption may sustain continued usage for a few more years. If the equipment is susceptible to leaks either implement a leakage reduction campaign or replace the equipment and use a new refrigerant. Annual consumption can be checked by consulting purchasing and maintenance records.

3.4 Step 3 - Review Options

OPTION 1: *Continue using existing plant:*

If a refrigeration system is leak free, use of the existing refrigerants can continue, providing an emergency plan is established to take care of a plant failure.

OPTION 2: *Leakage reduction:*

Many refrigeration plants leak. It will prove impossible to continue use of existing plants unless levels of leakage are considerably reduced.

OPTION 3: *Refrigerant recovery and re-use:*

Whenever an old plant is being decommissioned or a plant is being serviced **it is essential that the refrigerant is recovered.** During the recovery process it is important that refrigerant is transferred into a cylinder that is empty or that **contains the same type of refrigerant.**

Refrigerant should only be handled by a qualified refrigeration engineer or accredited refrigeration technician.

OPTION 4: *Using alternative refrigerants:*

The most important factors in selecting a refrigerant to replace a chlorinated refrigerant are low ozone depletion potential, low global warming potential, high efficiency and safety of use.

It should be noted that all refrigerants must be used with caution. For further information refer to the manufacturer of the refrigerant.

PART 4: REDUCING THE IMPACT ON GLOBAL WARMING

4.1 Introduction

As already mentioned in part 1 of this guide an acceptable method of estimating the total effect on global warming is by considering the direct and indirect effects of refrigerants considered for use in a system. It should be noted that the system design and components selected to operate in a refrigeration system have a great deal of impact on the indirect global warming potential of a system. This section provides an overview to reduce the impact on global warming of refrigeration systems.

4.2 Direct Emissions

Direct emissions are made up of two components; refrigerant leakage and refrigerant recovery losses. ***Code of Good Practice HB40 Part 1 "Reduction of Emissions of Fluorocarbon Refrigerants in Commercial and Industrial Refrigeration and Air Conditioning Systems" provides guidelines for designers and installers to improve system design and reduce refrigerant loss from a system.***

GLOBAL WARMING POTENTIAL:

Global Warming Potential (GWP) of a refrigerant is an indicator of its potency to warm the planet by action as a greenhouse gas. The values shown in the environmental properties tables of this guide are relative to Carbon Dioxide (CO_2) for integration periods of 20 and 100 years respectively. The GWP values shown for blends are mass-weighted averages.

As Direct Global Warming Potential is determined by the amount of refrigerant permitted to escape to atmosphere it must be realised that the more environmentally friendly the refrigerant (lowest GWP) the less damaging the long term effect of the substance on the environment.

LEAKAGE AND RECOVERY LOSSES:

Each type of equipment or installation has its own characteristics in terms of refrigerant “consumption”. Fugitive emissions, leak-tightness degradation, ruptures, losses during handling and lack of recovery at the end of life are not the same for each application. The levels of emission will differ for each system. Some can consume several times their initial charge of refrigerant over their lifetime. Other systems can have near zero leakage.

Preventive actions aim at sharply decreasing emissions (design and installation phase). They consist of (1) refining the designs of all components that may contribute to leak tightness, (2) charge reduction and (3) limitation of incidents that cause losses by rupture or relief valves opening. The reduction, even elimination, of refrigerant recharge for these highly refined systems should be the objective of all installation.

MEANS TO LIMIT EMISSIONS:

Improving leak tightness is essentially a conservation measure that takes into consideration the intrinsic characteristics of assemblies and materials, as well as unpredictable events such as leak-tightness degradation and ruptures.

Emission reduction is not limited to improving leak tightness or recovering refrigerant it is an overall discipline that applies to the entire life-cycle of the product.

MEANS TO LIMIT EMISSIONS (cont.)

Emission limitation profoundly affects each process, such as charging or recovery, in which the refrigerant is handled, as well as all procedures performed on systems or parts of systems that contain refrigerants. Emission limitation also requires:

- ✓ A commitment by management to implement such policy in designing, operating or servicing systems;
- ✓ Design of very tight systems;
- ✓ Implementation of metrology for measuring leak flow rates;
- ✓ Implementation of leak-tightness classification of components such as joints, valves and flexible hoses;
- ✓ Enforcement of “no venting” handling procedure;
- ✓ Availability of adequate high-quality equipment (detectors, area monitors, recovery units, adaptors, connection hoses etc);
- ✓ Use of simple documentation to trace refrigerant movement;
- ✓ Definition of refrigerant-saving operation and maintenance procedures;
- ✓ Training technicians in refrigerant leak-tightness control and recovery.

Recommendations to reduce refrigerant leakage vary depending on whether installations are fixed or mobile.

For fixed installations, key points that result in an improved leak-tight installation are:

- ✓ Minimisation of the refrigerant charge of a system;
- ✓ Selection of a refrigerant and design a system to operate at lower operating pressures;
- ✓ Minimisation of the number of connections in a system;
- ✓ Incorporation of welded joints and fittings instead of screwed joints and fittings;
- ✓ Limitation of emission from relief valves (refer Code of Good Practice HB40 part 1, clause 4.5.4);
- ✓ Selection of sealed or semi-hermetic equipment in favour of open drive plant;
- ✓ Selection of sealed components less prone to refrigerant leakage;
- ✓ Carrying out of extensive pressure testing before evacuating the system (refer AS 1677 part 2, clause 5.1).
- ✓ Evacuation of each system using the deep evacuation or triple evacuation method (refer Code of Good Practice HB40 part 1, clause 8.2). Please note that the lower the vacuum pressure the more likely the system will be without leaks;
- ✓ Use of compatible elastomers and gasketting materials;
- ✓ Provision of refrigerant detectors in plant areas with early warning

alarms.

4.3 Indirect Emissions

Indirect Emissions are the major contributor to a refrigeration system's global warming effect caused by the energy consumption of a system. Based on the high percentage of fossil fuels used in power stations the CO_2 could be as high as 0.8 kg per kWhr of electrical energy. This results in a significant greenhouse effect over the life of the plant. Small improvements in system efficiencies therefore have a marked improvement on the global warming impact of a refrigerant system. The following provides an overview of the various proven methods used to reduce energy consumption of a refrigerant system.

REFRIGERANT PERFORMANCE:

From the viewpoint of economic operation and low energy consumption (i.e. low global warming impact) it is desirable that a refrigerant has physical and thermal characteristics that will result in a minimum power requirement per unit of refrigerating capacity - that is, a high coefficient of performance. The more important properties of a refrigerant that influence the capacity and efficiency are (1) the latent heat of vapourisation, (2) the specific volume of vapour, (3) the compression ratio and (4) the specific heat of the refrigerant in both liquid and vapour states. Except in very small systems, a very high latent heat value is desirable in that the mass flow rate per unit of capacity is less. When a high latent heat value is accompanied by a low specific volume in the vapour state, the efficiency and capacity of the compressor are greatly increased. This not only decreases power consumption but also reduces the compressor displacement requirements that permit the use of smaller, more compact equipment. However in small systems, if the latent heat value of the refrigerant is too high, the amount of refrigerant circulated will be insufficient for accurate control of liquid. All other factors being equal, the refrigerant giving the lowest compression ratio is the most desirable. Low compression ratios result in low power consumption and high volumetric efficiency, the latter being more important in smaller systems since it permits the use of small compressors.

HEAT EXCHANGERS:

Heat exchangers such as evaporators and condensers benefit from an improved coefficient of conductance, as heat transfer rates improve, particularly in liquid chilling applications. It is also desirable that the pressure - temperature relationship of the refrigerant is such that the pressure in the evaporator is always above atmospheric. If the pressure in the low pressure side is below atmospheric pressure, it is possible for considerable amounts of air and moisture to be drawn into the system in the event of a leak. Reasonably low condensing pressures under normal atmospheric conditions are also desirable in that they allow the use of light weight materials in construction of the condensing equipment, thereby reducing the size, weight and cost of the equipment.

EVAPORATING TEMPERATURE:

Compressor performance and cycle efficiency varies considerably with the operating conditions of the system. The most important factor governing compressor capacity is the vapourising temperature of the liquid in the evaporator - that is the suction or evaporating temperature of a system.

The large variations in compressor capacity that accompany changes in the operating suction temperature are primarily a result of change in the density of the suction vapour entering the compressor. The higher the vapourising pressure, the greater the density of the suction vapour. A given volume of suction vapour, handled by the compressor represents a greater mass of refrigerant when the suction pressure is high than when the suction pressure is low. This means that for any given piston displacement, the mass circulated by the compressor per unit of time increases as the suction pressure increases. A higher suction pressure will result in lower energy consumption of a refrigerating system.

CONDENSING TEMPERATURE:

The refrigerating capacity of a compressor decreases as the condensing temperature increases. Increasing the condensing temperature while the suction temperature remains constant increases the compression ratio and reduces the volumetric efficiency of the compressor so that the actual volume of vapour displaced by the compressor per unit of time decreases. Therefore, even if the density of the vapour entering the compressor were to remain the same at all condensing temperatures, the actual mass of refrigerant circulated by the compressor per unit of time would decrease because of the reduction in compressor displacement. Heat rejection dependent on wet bulb temperature can present an advantage over dry bulb temperature dependent heat rejection equipment.

COMPRESSOR EFFICIENCY:

Compressor technology is changing and compressor efficiencies are constantly improving. In addition there are a number of alternative compressor types available on the market today, all of which have differing performance characteristics and efficiencies. Some available compressor types are (1) reciprocating compressors, (2) rotary compressors, (3) centrifugal compressors, (4) screw compressors and (5) orbital or scroll compressors. All compressor types have certain advantages in their own field of use. For the most part, the type of compressor employed in any individual application depends on the size and nature of the installation and on the refrigerant used in the system. Considerable compressor power can be saved by investigating available alternatives and selecting the most appropriate compressor for the application.

PIPE SIZING:

In sizing refrigerant pipes, cost considerations favour keeping line sizes as small as possible. However, suction and discharge line pressure drops cause loss of compressor capacity and increase energy consumption. Excessive liquid line pressure drops cause flashing of the liquid refrigerant, resulting in faulty expansion valve operation. Refrigerant lines should be sized for pressure losses of 1K or less per segment of the discharge, suction and liquid line piping.

PART 5: IMPLEMENTATION

5.1 Introduction

After the options have been reviewed those that are appropriate can now be implemented. It is important to remember that the refrigeration contracting industry has limited capacity. To ensure that there is no lack of refrigeration, immediate action must be taken**.** It is necessary that a **REFRIGERANT MANAGEMENT PROGRAM** be established without delay.

This will include a combination of several of the options described. It will allow maximum possible operation of the existing plant and equipment, whilst ensuring that the phase out occurs in a controlled way with minimum risk to the facility and the environment.

The elements of a Refrigerant Management Program should include:

1. Minimising leaks and ensuring no refrigerant is being vented to atmosphere;

2. Identifying which equipment can be converted or replaced most easily/cheaply and which plant is old and due for replacement anyway;

3. In year one (1) converting or replacing enough equipment to supply sufficient recovered refrigerants for annual servicing requirements for the remaining equipment;

4. In year two (2) and beyond, continuing the process until all plant and equipment has been converted to **Ozone Benign** refrigerants. The investment cost for conversion and/or replacement of existing equipment operating on ODS can be spread over several years by adopting the above steps. Benefits can also be gained from new technology, equipment and refrigerant developments.

Options can be reviewed and strategies can be modified as new refrigerants or technologies become available on the market. In some instances, such as CFC 11 chiller systems, it is not possible to convert the plant to operate on an ozone benign refrigerant. Equipment of this type should, if possible, be converted to a low ozone depleting HCFC refrigerant until such time as an ozone benign replacement becomes available. HCFC123 would in this instance be considered the most suitable replacement refrigerant for R11 systems. R123 has a low ODP, low GWP and has a high efficiency.

Your assessment of a suitable replacement refrigerant should include the following:

SAFETY:

All refrigerants used in the air conditioning and refrigeration industry are potentially dangerous and require different safety procedures and provisions. Ongoing use, design development and tests for safety change the requirements and safety provisions for each respective refrigerant. In some instances it may be necessary to provide additional refrigerant detection and oxygen level detection systems to ensure that the plant provides a safe operating environment to the operators and occupants.

COMPATIBILITY :

When selecting a replacement refrigerant for an existing system it is necessary to check the compatibility of the fluid with existing system components and operating conditions such as operating pressures, lubricants used, motor insulation, component seals and the like.

AVAILABILITY:

It is necessary to ensure that the selected refrigerant is commercially available in the short, medium and long term.

COST:

As the cost of refrigerants varies with supply and demand it is necessary to check the cost of both the first and second choice refrigerants to ensure that future purchases of replacement refrigerants remain affordable.

PART 6: SAFETY GROUP CLASSIFICATIONS

6.1 Introduction

Refrigerants have been classified into safety groups according to the following criteria:

Classification: The safety classifications consist of two alphanumeric characters (e.g. A2 or B1). The capital letter indicates the toxicity and the Arabic numeral denotes the flammability.

Toxicity classification: Refrigerants are assigned to one of two classes: A or B based on the following exposure:

> ***Class A*** signifies refrigerants for which toxicity has not been identified at concentrations less than or equal to 400 ppm, based on data used to determine Threshold Limit Value-Time-Weighted Average (TLV-TWA) or consistent indices.
>
> ***Class B*** signifies refrigerants for which there is evidence of toxicity at concentrations below 400 ppm, based on data used to determine TLV-TWA or concentration indices.

Flammability Classification: Refrigerants are assigned to one of three classes: 1, 2 or 3 based on flammability. Tests have been conducted in accordance with ASTM E681-85 except that the ignition source shall be an electrically activated kitchen match head for halocarbon refrigerants.

> ***Class 1*** indicates refrigerants that do not show flame propagation when tested in air at 101 kPA (standard atmospheric pressure) and 21^{o}C.
>
> ***Class 2*** signifies refrigerants having a lower flammability limit (LFL) concentration of more than 0.10 kg/m^3 in air at 21^{o}C and 101 kPa and a heat of combustion of less than 19,000 kJ/kg. The heat of combustion has been calculated assuming that combustion products are gaseous and in their most stable state (e.g. C, N, S give CO_2, N_2, SO_3; F and Cl give HF and HCl if there is enough H in the molecule, otherwise they give F_2 and Cl_2; excess H is converted to H_2O).
>
> ***Class 3*** indicates refrigerants that are highly flammable, as identified by an LFL concentration of less than or equal to 0.10 kg/m^3 at 21^{o}C and 101 kPa or a heat of combustion greater than or equal to 19,000 kJ/kg. The heat of combustion is calculated as explained above in the definition of a class 2 category.
>
> Definitions of flammability differ depending on the purpose. For example, ammonia is classified for transportation purposes as a non-flammable gas by the U.S. Department of Transportation, but it is a Class 2 refrigerant.

Safety Classification of Refrigerant Blends: Blends, whose flammability and/or toxicity characteristic may change as the composition changes during fractionation, shall be assigned a dual safety group classification with the two classifications separated by a slash (/). Each of the two classifications has been determined according to the same criteria as a single component refrigerant. The first classification listed is the classification of the ‘as formulated’ composition of the blend. The second classification is the classification of the blend composition of the ‘worst case fractionation’. For flammability, ‘worst case of fractionation’ is defined as the composition during fractionation that results in the highest concentration of the flammable component(s) in the vapour or liquid phase. For toxicity, ‘worst case of fractionation’ is defined as the composition during fractionation that results in the highest concentration(s) in the vapour or liquid phase for which the TLV-TWA is less than 400 ppm. The TLV-TWA for a specified blend composition has been calculated from the TLV-TWA of the individual components.

PART 7: FLUORINATED REFRIGERANTS

7.1 Introduction

The availability of chlorinated refrigerants to service existing plant is now becoming unreliable. Equipment owners should ensure their CFC/HCFC based equipment is made leak free, converted or replaced immediately. The conversion/retrofitting options available for the air conditioning and refrigeration industry can be summarised as follows. If equipment is normally leak free, such as domestic refrigerators, there is no need to convert the system. The equipment can live out its commercial life with the original charge, as there is no requirement to withdraw chlorinated refrigerants from service. Alternatives for new equipment are not confined to HCFC and HFC refrigerants. Consideration should be given to other technologies and refrigerants such as ammonia, hydrocarbons, absorption and the like.

The following table summarises the manufacturers' recommendations for retrofit and new equipment replacement refrigerants. The final application of refrigerants should be checked for compatibility with equipment and system design. A thorough investigation should be undertaken with both refrigerant suppliers and equipment manufacturers to ensure replacement or alternative refrigerants are fully compatible with and suitable for the application and system design.

SECTOR	COMPRESSOR TYPE	REFRIGERANT
Domestic fridge/Freezers	Sealed hermetic unit	R134a, R401A, R409A. R413A
Commercial equipment – medium temperature	Sealed hermetic unit	R134a, R22, R401A[1], R404A, R407A, R409A, R413A, R507
	Accessible semi-hermetic	R134a, R22, R401A[2], R404A, R407C, R413A, R507
	Reciprocating open drive	R134a, R22, R401A[2], R404A, R407C, R409A[2], R413A, R507
Commercial equipment - low temperature	Sealed hermetic unit	R22, R402A, R402B, R403A, R404A, R407B, R408A, R410A, R507
	Accessible semi-hermetic	R22, R402B, R403A, R404A, R407B, R408A, R410A, R507
	Reciprocating open drive	R22, R402A, R402B, R403A, R404A, R407B, R408A, R410A, R507
Large commercial and industrial	Reciprocating Open drive	R22, R134a, R401A, R401B, R402A, R403A, R404A, R407B[4], R407C[4], R408A, R409A, R410A, R413A, R507, R717
	Centrifugal/screw	R134a, R123, possibly R124[3] , R22, R407A[4], R401A[4], R717
Mobile air conditioning or refrigeration	Reciprocating Open drive	R22, R134a, R401C, R402A, R403A, R404A, R407C, R408A, R409A, R409B, R416A, R507, possibly R22
Air conditioning	Reciprocating Open drive	R22, R134a, R401A, R409A, R410A, R413A
	Centrifugal/screw	R134a, R123, R22, R410A
	Accessible semi-hermetic	R22, R123, R134a, R401B, R404A, R407C, R409B, R410A, R507

NOTES:

[1] R401A for Evaporating temperatures between -23°C and 7°C

[2] R401A and R409A are not suitable for beverage coolers i.e. Temprite, Drinkrite coolers etc

[3] usually extensive modifications required

[4] not for use with flooded evaporators

- The above table provides an overview of alternative refrigerant option. It is recommended that final selection and performance details are verified with the refrigerant supplier and equipment manufacturer before any work is undertaken.

7.2 Selecting an Ozone Friendly Refrigerant

The numerous “alternative” refrigerants available on the market today present a somewhat confusing situation for designers and contractors. ANSI/ASHRAE Standard 34 provides a refrigerant numbering system assigning composition-designating prefixes for the various refrigerant groups. ASHRAE refrigerant number groups are as follows:

- R10 to R50 are Methane Series Refrigerants;
- R110 to R170 are Ethane Series Refrigerants;
- R216ca to R290 are Propane Series Refrigerants;
- RC316 to RC318 are Cyclic Organic Compound Refrigerants;
- R400 to R411B are Zeotropic Blend Refrigerants *;
- R500 to R509 are Azeotropic Blend Refrigerants;
- R600 to R620 are Miscellaneous Organic Compound Refrigerants;
- R630 and R631 are Nitrogen Compounds;
- R702 to R764 are Inorganic Compounds and;
- R1112a to R1270 are Unsaturated Organic Compounds.

* Zeotropic Blend refrigerants that are commercially available have been assigned an identifying number in the 400 Series. This number designates which components are in the mixture but not the proportion of each. The letter added to the refrigerant number distinguishes between zeotropic blends having the same components in different proportions.

Replacement refrigerants can be segregated into two distinct categories transitional or retrofit refrigerants and medium and long term refrigerants:

7.3 Transitional or Retrofit Refrigerants

Transitional or Retrofit refrigerants are HCFC (hydrochlorofluorocarbon) refrigerants which also contain reduced amounts of Chlorine. They are primarily intended as substitute refrigerants for systems that use CFC refrigerants.

These refrigerants should be considered as an interim medium term alternative and not a long term replacement refrigerant, as substantive supply (imports) will cease by 2020 with only very limited supplies then available until 2030 to service remaining HCFC-dependent equipment, in accordance with the *Montreal Protocol* and the *Ozone Protection Act*.

7.4 Medium and Long Term Refrigerants

Chlorine free refrigerants are considered long term substitutes for ozone depleting refrigerants. HFC (hydrofluorocarbon) refrigerants available in Australia have a zero ozone depletion potential (ODP) and generally have a relatively low global warming potential (GWP).

7.5 Refrigerant Performance Characteristics

Refrigerant properties are necessary to describe the operating characteristics of the refrigerant within the system. Thermodynamic and transport properties of refrigerants are necessary for predicting system behaviour and component performance. The following table provides the basic performance properties of halogenated refrigerants:

Refrigerant:	**Mol. Mass:** (kg/kmol)	**Freezing Point:** (^oC)	**Normal Boiling Point at 1 Atm:** (^oC)	**Critical Temperature:** (^oC)	**Critical Pressure:** (kPa, abs)
CFC's:					
R11	137.38	-110.5	23.71	198.0	4,408
R12	120.91	-157.1	-29.75	112.0	4,136
R113	187.38	-36.22	47.59	214.1	3,392
R114	170.92	-94.2	3.6	145.7	3,257
R500	99.30	-159	-33.5	102.1	4,173
R502	111.6	-	-45.4	80.73	4,018
HCFC's:					
R22	86.48	-160	-40.76	96.0	4,974
R123	152.93	-107.15	27.82	183.68	3,662
R124	136.47	-199.15	-11.96	122.3	3,624
R401A	99.44	-	-34.4	105.3	4,613
R401B	92.84	-	-35.7	103.5	4,682
R401C	101.0	-	-22.9	109.9	4,402
R402A	101.6	-	-49.2	76.03	4,234
R402B	94.71	-	-47.2	83.0	4,525
R403A	91.99	-	-44.0	91.2	4,690
R403B	103.26	-	-43.8	88.7	4,400
R405A	111.9	-	-32.9	106.0	4,292
R406A	89.86	-	-32.7	116.5	4,883
R408A	87.01	-	-45.5	83.3	4,424
R409A	97.43	-	-35.4	106.9	4,699
R409B	96.67	-	-36.5	104.4	4,711
R411A	82.36	-	-39.7	99.1	4,954
R411B	83.07	-	-41.6	96.0	4,947
R412A	92.17	-	-36.4	107.5	4,880
R416A	111.9	-	-24.7	111.9	4,015
R509A	123.96	-	-40.4	87.2	4,030
HFC's:					
R125	120.2	-100.63	-48.14	66.2	3,629
R134a	102.03	-103.3	-26.07	101.1	4,059
R404A	97.60	-	-46.6	72.1	3,735
R407A	90.11	-	-45.2	81.9	4,487
R407B	102.94	-	-46.8	74.4	4,083
R407C	86.20	-	-43.8	86.1	4,634
R410A	72.59	-	-51.6	70.2	4,770
R413A	103.95	-	-29.3	101.4	4,240
R417A	106.70	-	-41.8	89.9	4,096
R507A	98.86	-	-47.1	70.8	3,715

7.6 Environmental Properties

A long term replacement refrigerant should have zero or a low ozone depletion potential, a low global warming potential and a short estimated atmospheric life.

No:	Name:	Chemical Formula or %Mass Mixture:	O.D.P.:	G.W.P.: 20; 100; 500 yrs	Safety Classification
CFC's:					
R11	Trichlorofluoromethane	$C.Cl_3.F$	1.00	6,300; **4,600**; 1,600	A1
R12	Dichlorodifluoromethane	$C.Cl_2.F_2$	0.95	10,200; **10,600**; 5,200	A1
R113	Trichlorotrifluoroethane	$C.Cl_2.F.C.Cl.F_2$	0.85	6,100; **6,000**; 2,700	A1
R114	Dichlorotetrafluoroethane	$C.Cl.F_2.C.Cl.F_2$	0.70	7,500; **9,800**; 8,700	A1
R500	CFC Blend	CFC-12 (74%) HFC-152a (26%)	0.70	7,700; **7,900**; 3,90	A1
R502	CFC Blend	CFC-115 (51%) HCFC-22 (49%)	0.23	4,900; **4,500**; 5,300	A1
HCFC's:					
R22	Chlorodifluoromethane	$C.H.Cl.F_2$	0.055	4,800; **1,700**; 540	A1
R123	Dichlorotrifluoroethane	$C.H.Cl_2.C.F_3$	0.020	390; **120**; 36	A1
R124	Chlorotetrafluoroethane	$CH.F.Cl.C.F_3$	0.022	2,000; **620**; 190	A1
R401A	HCFC Blend	HCFC-22 (53%) HCFC-124 (34%) HFC-152a (13%)	0.037	3,300; **1,100**; 400	A1/A1
R401B	HCFC Blend	HCFC-22 (61%) HFC-124 (28%) HFC-152a (11%)	0.040	3,500; **1,200**; 400	A1/A1
R401C	HCFC Blend	HCFC-22 (33%) HFC-124 (52%) HFC-152a (15%)	0.030	2,700; **900**; 300	A1/A1
R402A	HCFC Blend	HCFC-22 (38%) HFC-125 (60%) HC-290(Propane) (2%)	0.021	5,400; **2,700**; 900	A1/A1
R402B	HCFC Blend	HCFC-22 (60%) HFC-125 (38%) HC-290(Propane) (2%)	0.033	5,100; **2,300**; 700	A1/A1
R403A	HCFC Blend	HCFC-22 (75%) HFC-218 (20%) HC-290(Propane) (5%)	0.041	4,800; **3,000**; 3000	A1/A1
R403B	HCFC Blend	HCFC-22 (56%) HFC-218 (39%) HC-290(Propane) (5%)	0.030	5,000; **4,300**; 5,100	A1/A1

No:	Name:	Chemical Formula or %Mass Mixture:	O.D.P.:	G.W.P.: 20; 100; 500 yrs	Safety Classification
R405A	HCFC Blend	HCFC-22 (45%) HFC-142b (5.5%) HFC-152a (7%) HFC-318 (42.5%)	0.028	5,200; **5,000**; 6,400	A1/A1
R406A	HCFC Blend	HCFC-22 (55%) HCFC-142b (41%) HC-600a(Isobutane) (4%)	0.057	3,500; **1,200**; 400	A1/A2
R408A	HCFC Blend	HCFC-22 (47%) HFC-125 (7%) HFC-143a (46%)	0.026	4,900; **2,800**; 1,000	A1/A1
R409A	HCFC Blend	HCFC-22 (60%) HCFC-124 (25%) HCFC-142b (15%)	0.048	4,200; **1,500**; 500	A1/A1
R409B	HCFC Blend	HCFC-22 (65%) HCFC-124 (25%) HCFC-142b (10%)	0.039	4,100; **1,500**; 500	A1/A1
R411A	HCFC Blend	HCFC-22 (87.5%) HCFC-152a (11%) HCFC-1270 (1.5%)	0.048	4,200; **1,500**; 500	A1/A2
R411B	HCFC Blend	HCFC-22 (94%) HCFC-152a (3%) HCFC-1270 (3%)	0.052	4,500; **1,600**; 500	A1/A2
R412A	HCFC Blend	HCFC-22 (70%) HCFC-142b (25%) HFC-218 (5%)	0.055	5,000; **2,200**; 1,200	A1/A2
R416A	HCFC Blend	HCFC-124 (39.5%) HCFC-134a (59%) HFC-600 (1.5%)	0.009	2,700; **1,000**; 300	A1/A1
R509A	HCFC Blend	HCFC-22 (44%) HFC-218 (56%)	0.024	5,400; **5,600**; 7,200	A1
HFC's:					
R125	Pentafluoroethane	$C_2.H.F_5$	0.0	5,900; **3,400**; 1,100	A1
R134a	Tetrafluoroethane	$C.F_3.C.H_2.F$	0.0	3,300; **1,300**; 400	A1
R404A	HFC Blend	HFC-125 (44%) HFC-134a (4%) HFC-143a (52%)	0.0	5,600; **3,800**; 1,300	A1/A1
R407A	HFC Blend	HFC-32 (20%) HFC-125 (40%) HFC-134a (40%)	0.0	4,000; **2,000**; 600	A1/A1
R407B	HFC Blend	HFC-32 (10%) HFC-125 (70%) HFC-134a (20%)	0.0	5,000; **2,700**; 900	A1/A1

No:	Name:	Chemical Formula or %Mass Mixture:	O.D.P.:	G.W.P.: 20; 100; 500 yrs	Safety Classification
R407C	HFC Blend	HFC-32 (23%) HFC-125 (25%) HFC-134a (52%)	0.0	3,600; **1,700**; 500	A1/A1
R410A	HFC Blend	HFC-32 (50%) HFC-125 (50%)	0.0	3,900; **2,000**; 600	A1/A1
R413A	HFC Blend	HFC-134a (88%) HFC-218 (9%) HC-600a (3%)	0.0	3,400; **1,900**; 1,500	A1/A2
R417A	HFC Blend	HFC-125 (46.6%) HFC-134a (50%) HC-600 (3.4%)	0.0	4,400; **2,200**; 700	A1/A2
R507A	HFC Blend	HFC-125 (50%) HFC-143a (50%)	0.0	5,700; **3,900**; 1,400	A1

NOTES:

- **O.D.P.** referenced to Ozone Depletion Potential of CFC-11 (i.e. O.D.P. of CFC-11 = 1.0).
- **G.W.P.** referenced to the absolute global warming potential for CO_2 using time horizons of 20, 100 and 500 years. The **bold** figures refer to the 100 year time horizon commonly used as the inventory standard. Calculated GWP values for refrigerant blends have been rounded to the nearest 100.
- **SAFETY GROUP CLASSIFICATIONS** as noted in AS 1677 part 1 are indicated by alphanumeric characters (e.g. A1, A2, B3 etc). The capital letters A or B indicate lower or higher toxicity respectively and the numeric value refers to the refrigerant’s flammability (the number 1 being no flame propagation and 3 being higher flammability).

7.7 Refrigerant Performance

As all refrigerants perform differently, it is necessary to check the performance characteristic of each alternative refrigerant being considered for a particular system.

A full comparative performance analysis should be based on identical operating conditions (such as evaporating and condensing temperatures) and should include Coefficient of Performance, Compression Ratio, Mass Flow Rate and Temperature Glide. All comparisons should be based on a standard method such as that published by ASHRAE.

A variation in operating conditions will result in a meaningless comparison. Should a refrigerant be selected as a replacement refrigerant for an existing system, it will then be necessary to include the existing refrigerant in the comparative analysis. Performance characteristics of fluorinated refrigerants and blends, based on ASHRAE conditions have been included in appendix C of this guide.

7.8 Refrigerants, Lubricants and System Considerations

New generation refrigerants, in some instances, are more dependent on the correct application and type of refrigerant oil. Particular care should therefore be taken to ensure that the replacement refrigerant and compressor manufacturers' requirements are satisfied and conversion procedures (if necessary) are adopted.

HCFC-123

Is classed as a low pressure refrigerant, designed to replace CFC-11 in centrifugal chillers. HCFC-123 is compatible with most material used on CFC-11 systems (including refrigerant oil) with the exception of some motor insulation and gasketing materials.

HCFC-123 has been subjected to rigorous analysis by the National Industrial Chemical Notification and Assessment Scheme (NICNAS), a division of Worksafe Australia in their Priority Existing Chemical No. 4 report dated March 1996.

The report indicates that HCFC-123 should be classified as Carcinogenic (Category 3). Toxicity testing of HCFC-123 has indicated caution is needed with long term exposure in the work place.

HFC-134a

Operates at pressures similar to CFC-12 and it is compatible with most materials in CFC-12 systems. However, different HFC-134a driers are required and other minor system changes may be necessary. HFC-134a will not operate with the conventional mineral oils used with CFC-12. The industry has elected in most cases to use a synthetic polyol ester lubricant in new HFC-134a systems.

Polyol ester lubricants absorb moisture at a much greater rate than mineral oils and thus should not be left open to the atmosphere more than the absolute minimum. CFC-12 and the mineral oils used in CFC-12 systems are compatible with polyol ester lubricants, enabling existing CFC-12/mineral oil systems to be retrofitted to HFC134a/polyol ester. Polyol ester lubricants should be stored in metal containers as moisture can penetrate some plastic containers.

The only deviation from the above is the automotive industry where PAG (poly alkylene glycol) oils are recommended for new compressors and occasionally for retrofit. PAG oils absorb moisture ten times more readily than polyol ester lubricants. PAG oils are not generally compatible with either CFC-12 or mineral oil and so are not usually suitable for retrofits.

R401A

Is an HCFC blend or mixture refrigerant designed to replace CFC-12 refrigerant in existing systems, with evaporating temperatures between - 23 °C and - 7 °C, and is compatible with most materials in CFC-12 systems. Drier cores may require upgrading or changing and other minor design changes may be necessary.

It is recommended that 50% of the mineral oil in existing systems be replaced with alkyl benzene lubricant (polyol ester oil may be used). Alkyl benzene does not readily absorb moisture and can therefore be handled in the same way as mineral oil.

R401B

Is an HCFC blend or mixture refrigerant designed to replace CFC-12 refrigerants in existing systems with evaporating temperatures between -40 °C and -23 °C. It is recommended that 50% of the mineral oil in the existing CFC-12 systems be replaced with alkyl benzene lubricant (polyol ester oil may be used). Alkyl benzene lubricant does not readily absorb moisture and can therefore be handled in the same way as mineral oil. Drier cores may require upgrading or changing and other minor system changes may be necessary.

R401C

Is an HCFC blend or mixture refrigerant designed to replace CFC-12 in existing automotive air conditioning systems.   The receiver/drier should be replaced with a suitable desiccant core and the flexible hoses should be replaced with nylon barrier hoses. It is not necessary to flush mineral oil from the system, but it is necessary that the 55cc's of alkyl benzene lubricant be added to replace the mineral oil lost during evacuation of the CFC-12 and also in the receiver/drier.

R402A	Is an HCFC blend or mixture refrigerant designed to replace CFC-502 refrigerant. R402A is compatible with most materials in CFC-502 systems. Drier cores may require upgrading or changing and other minor system changes may be necessary. The manufacturers recommend that 50% of the mineral oil in existing systems be replaced with alkyl benzene lubricant. Alkyl benzene does not absorb moisture.
R402B	Is an HCFC blend or mixture refrigerant designed to replace CFC-502 in existing small hermetic systems, such as ice-making machines. No oil changes are necessary and only the filter driers need to be changed to a suitable desiccant core.
R403A	Is an HCFC blend or mixture refrigerant designed to replace CFC-502 refrigerant. R403A is compatible with most materials in CFC-502 systems and will operate with conventional mineral oils used with CFC-502 refrigerants.
R403B	Is an HCFC blend or mixture refrigerant designed to replace CFC-502 refrigerant. R403B is compatible with most materials in CFC-502 systems and will operate with conventional mineral oils used with CFC-502 refrigerants.
R404A	Is an HFC blend or mixture refrigerant designed to replace CFC-502. R404A is compatible with most materials used in CFC-502 systems. These refrigerants will not operate with conventional mineral oils used with CFC-502 refrigerants unless the system is specifically designed to recover an immiscible oil to the compressor. The manufacturers recommend that polyol ester lubricants be used. These refrigerants can be used as replacement refrigerants for R502 in existing systems. However, since they are all HFC based, it will be necessary to remove the existing mineral oil to less than 5% by flushing with polyol ester oils. Polyol ester oils readily absorb moisture and cannot be left open to the atmosphere without detrimental effects. Drier cores may require replacing or changing and other minor system changes may be necessary.
R405A	Is an HCFC blend or mixture refrigerant designed to replace CFC-12 refrigerant. R405A is compatible with most materials in CFC-12 systems and will operate with conventional mineral oils used with CFC-12 refrigerants.
R406A	Is an HCFC blend or mixture refrigerant designed to replace CFC-12 refrigerant. R406A is compatible with most materials in CFC-12 systems and will operate with conventional mineral oils used with CFC-12 refrigerants.
R407A	Is an HFC blend or mixture refrigerant designed as a replacement refrigerant for CFC-12 systems. Drier cores may require upgrading or changing and other minor system changes may be necessary. The manufacturer recommends that polyol ester lubricant is used with R407A refrigerants.

R407B	Is an HFC blend or mixture refrigerant designed as a replacement refrigerant for CFC-12 and CFC-502 systems. Drier cores may require upgrading or changing and other minor system changes may be necessary. The manufacturer recommends that polyol ester lubricant is used with R407B refrigerants.
R407C	Is an HFC blend or mixture refrigerant designed as a replacement refrigerant for HCFC-22. Drier cores may require upgrading or changing and other minor system changes may be necessary. The manufacturer recommends that polyol ester lubricant is used with R407C refrigerants.
R408A	Is an HCFC blend or mixture refrigerant designed to replace CFC-502. R408A is compatible with most materials used in CFC-502 system and will operate with conventional mineral oils used with CFC-502 refrigerants. Polyol ester lubricants will, however, provide improved results. Drier cores may require replacing or changing and other minor system changes may be necessary.
R409A	Is an HCFC blend or mixture refrigerant designed to replace CFC-12. R409A is compatible with most materials used in CFC-12 systems. R409A will operate with conventional mineral and alkyl benzene lubricants. Drier cores may require replacing or changing and other minor system changes may be necessary.
R409B	Is an HCFC blend or mixture refrigerant designed to replace CFC-12. R409B is compatible with most materials used in CFC-12 systems. R409B can also be used as a replacement for R500, which is extensively used in transport refrigeration. R409B will operate with conventional mineral and alkyl benzene lubricants. Drier cores may require replacing or changing and other minor system changes may be necessary.
R410A	Is a near-azeotropic HFC blend refrigerant, designed to replace HCFC-22. However, its pressure is approximately 50% higher than HCFC-22 and therefore is not safe to use as a drop in replacement for HCFC-22. R410A is compatible with most materials used in HCFC-22 systems. Drier cores may require upgrading or changing and other minor system changes may be necessary. R410A will not operate with conventional mineral oils used in HCFC-22 systems. The manufacturer recommends that polyol ester lubricants are used in R410A systems.
R411A	Is an HCFC blend or mixture refrigerant designed to replace HCFC-22. R411A is compatible with most materials used in HCFC-22 systems and will operate with conventional mineral and alkyl benzene lubricants. Drier cores may require replacing or changing and other minor system changes may be necessary.

R411B

Is an HCFC blend or mixture refrigerant designed to replace CFC-502. R411B is compatible with most materials used in CFC-502 systems and will operate with conventional mineral and alkyl benzene lubricants. Drier cores may require replacing or changing and other minor system changes may be necessary.

R412A

Is an HCFC blend or mixture refrigerant designed to replace CFC-500. R412A is compatible with most materials used in CFC-500 systems. R412A will operate with conventional mineral and alkyl benzene lubricants. Drier cores may require replacing or changing and other minor system changes may be necessary.

R413A

Is an HFC blend or mixture refrigerant designed as a replacement refrigerant for CFC-12 systems. Drier cores may require upgrading or changing and other minor system changes may be necessary. R413A will operate with conventional mineral oils, polyol ester and poly alkylene glycol lubricants.

R416A

Is an HCFC blend or mixture refrigerant designed to replace CFC-12. R416A is compatible with most materials used in CFC-12 systems. R416A will operate with conventional mineral oil, alkyl benzene, polyol ester and polyol alkylene glycol lubricants. Drier cores may require replacing or changing and other minor system changes may be necessary.

R507

Is an azeotropic HFC blend refrigerant, designed to replace CFC-502 and is compatible with most materials used in CFC-502 systems. Drier cores may require upgrading or changing and other minor system changes may be necessary. R507 will not operate with conventional mineral oils used in CFC-502 systems. The manufacturer recommends that polyol ester lubricants are used in R507 systems.

7.9 Overview of Suitable Lubricants

The primary function of lubricants is to reduce friction and minimise wear in the compressor. A lubricant achieves this by interposing a film between sliding surfaces that reduces direct solid-to-solid contact or lowers the coefficient of friction.

Understanding the role of lubricants requires an analysis of surfaces to be lubricated and their potential interaction with refrigerants and other elastomers in the system. It is therefore essential that lubricants are selected and confirmed to be appropriate by equipment and refrigerant manufacturers.

Lubricants now in use and being considered for new refrigerants include mineral oils (MO), alkyl benzene (AB), poly-alpha-olefin (PAO), polyol-ester (POE), poly vinyl-ether (PVE), poly alkylene-glycol (PAG) and hydro-treated mineral oils. Lubricants containing silicone and silicate (additives used as anti-foaming agents) may not be compatible with new generation refrigerants. Compatibility of lubricants with new generation refrigerants is as follows:

Traditional Lubricants	CFC's & HCFC's	HFC's
Mineral oil (MO)	Good suitability	Not suitable
Alkyl benzene (AB)	Good suitability	Limited application
Mineral oil + Alkyl benzene	Good suitability	Not suitable

Poly alpha olefin (PAO)	Limited application	Not suitable
New Lubricants		
Polyol ester (POE)	Limited application [1, 2]	Good suitability
Poly vinyl ether (PVE)	Not suitable	Good suitability [3]
Poly alkylene glycol (PAG)	Not suitable	Limited application [2]
Hydro treated mineral oil	Not suitable	Not suitable

NOTES:

[1] denotes lubricant possibly requiring basic viscosity correction

[2] denotes lubricant that is especially critical with moisture

[3] denotes extensive test program

7.10 Handling Refrigerants

The following recommendations concerning the practical handling of refrigerants should also be considered:

- When charging zeotropic refrigerant blends, equipment should be charged with liquid. When vapour is taken from the charging cylinder, shifts in concentration may occur.

- Many blends contain at least one flammable component therefore the entry of air into the system must be avoided. A critical displacement of the ignition point can occur under high pressure when a high proportion of air is present. **Note:** most blends containing a flammable component are formulated so that the vapour is not flammable.

- The use of blends with a significant temperature glide is not recommended for systems with flooded evaporators or condenser for performance, not safety reasons.

7.11 Reclaiming, Recycling or Reprocessing Used Refrigerants

As the requirements of the *Montreal Protocol* took effect from 1 January 1996 (by preventing or controlling the manufacture, import and export of CFC and HCFC refrigerants) the need to increase the rate of reclaiming, recycling and reprocessing of used refrigerants became more demanding. Reclaimed, recycled and reprocessed refrigerants are exempt from the phase out controls and can therefore be used without contravening current legislation.

Refrigerant Reclaim Australia (RRA) was established as the Australian refrigeration and air conditioning industry's response to the *Montreal Protocol* and the problem of ozone depletion. The primary objective of the organisation is to recover, reclaim and destroy ozone depleting refrigerants thereby reducing the industry's impact on the environment. More recently, RRA has expanded its role to incorporate the recovery and safe disposal of HFC's and PFC's. RRA is a not-for-profit public benefit organisation that holds its funds in a tightly controlled trust.

Contractors are able to return unwanted refrigerant to their wholesalers. Once the recovered refrigerant is received and weighted the contractor receives a rebate from RRA by way of a credit from their wholesaler.

PART 8: NATURAL REFRIGERANTS

8.1 Introduction

Natural refrigerants provide alternatives to a number of CFC, HCFC and HFC refrigerants. In addition to their zero ozone depletion potential (ODP) and low or no global warming potential (GWP), they are compatible with common elastomer materials found in refrigerating systems and are soluble in conventional mineral oils. Since natural refrigerants contain no chlorine or fluorine atoms, they cannot undergo reaction with water and hence, do not form the corresponding strong acids that can lead to premature system failure.

With the introduction of ODS regulations and the introduction of climate change policy around the world it is considered likely that more refrigeration system designers and users will be turning to alternative natural refrigerants. The increased application of this technology will bring with it many technical and safety issues. People working in the refrigeration industry have relatively little practical and theoretical knowledge about natural and in particular hydrocarbon refrigerants. It is therefore in the interest of the industry to make available as much technical and safety information as possible. Much of the knowledge already exists and AIRAH has assembled some of this information in this Refrigerant Selection Guide, as well as some of the basic information necessary for engineers working with refrigeration systems using natural refrigerants and hydrocarbons.

This document is intended to highlight the differences between natural refrigerants and other refrigerants and to direct readers to the authoritative documents that should be consulted.

8.2 Are Hydrocarbon Refrigerants safe to use?

The most important concern regarding the adoption of hydrocarbons as a refrigerant is their flammability. It should be remembered that millions of tonnes of hydrocarbons are used safely every year throughout the world for cooking, heating, powering vehicles and as aerosol propellants. In these industries, procedures and standards have been developed and adopted to ensure the safe use of the product. It is essential that the same approach is followed by the refrigeration industry. Hydrocarbons do not spontaneously combust on contact with air. Three elements need to coincide:

1. There must be a release of hydrocarbons.
2. The hydrocarbon needs to mix with the correct proportion of air, the range of flammability being approximately between 1 and 10%. *Outside these limits combustion cannot occur.*
3. An ignition source with an energy greater than 0.25 millijoules or a surface with a temperature exceeding 440°C must be present.

Solutions to eliminate the scenario for potential fire or explosion can be summarised as follows:

1. Contain the hydrocarbon either in a sealed system and/or reduce the number of connections.
2. Restrict the maximum charge of hydrocarbons.
3. Install ventilation such that the final concentration of hydrocarbons in air is below the lower flammability limit.
4. Eliminate the source of ignition associated with the system.

Only one of these measures needs to be effective to prevent an incident.

8.3 Selection Guide for Natural Refrigerants

Refrigerants should be selected so that they contribute to good system efficiency.

The following table is provided as a guide for the selection of refrigerants for new equipment. The final application of alternative refrigerants should be checked for compatibility with equipment and system design. A thorough investigation should be undertaken with both refrigerant suppliers and equipment manufacturers to ensure refrigerants are fully compatible with, and are suitable for, the application and system design.

SECTOR	COMPRESSOR TYPE	REFRIGERANT	COMMENTS
Domestic fridge/ freezers	Sealed hermetic unit	R290, R600a,	
Commercial equipment - medium temperature	Sealed hermetic unit	R290, R600a	
	Accessible semi-hermetic	R290, R600a	
	Reciprocating open drive	R290, R600a	
Commercial equipment - low temperature	Sealed hermetic unit	R170, R290	
	Accessible semi-hermetic	R170,R290	
	Reciprocating open drive	R170, R290, R744	
	All	R170, R290, R744	
Large commercial and industrial	Reciprocating open drive	R170, R290, R600a, R717, R744	R717 is not compatible with copper piping or wiring.
	Screw	R600a, R290, R744	
	All	R600a, R290, R744	
Mobile air conditioning or refrigeration	Her metic reciprocating open drive	R600a, R290	
Air conditioning	Reciprocating open drive	R600a, R290, R717	
	Centrifugal	R600a	
	Accessible semi-hermetic	R290	
	Screw	R600a, R717	
	Hermetic	R600a	
	All	R290	

NOTES:

R744 (Carbon Dioxide) should only be considered for low temperature applications (-10^{o}C or lower operating temperatures).

R600a (Isobutane) possesses approximately 50% volumetric refrigerating capacity of R12 and R134a.

The above table provides an overview of alternative refrigerant option. It is recommended that final selection and performance details are verified with the refrigerant supplier and equipment manufacturer before any work is undertaken.

Only refrigerant grade products should be used for the above applications. Commercial grade hydrocarbons contain significant quantities of sulphur, water and other impurities that contribute to the degradation of oils that may shorten compressor life and invalidate equipment warranties.

8.4 Refrigerant Performance Characteristics

Refrigerant properties are necessary to describe the operating characteristics of the refrigerant within the system. Thermodynamic and transport properties of refrigerants are necessary for predicting system behaviour and component performance.

The following table provides the basic performance properties of natural refrigerants:

Refrigerant:	Mol. Mass: (kg/kmol)	Freezing Point: (^{o}C)	Normal Boiling Point at 1 Atm.: (^{o}C)	Critical Temperature: (^{o}C)	Critical Pressure: (kPa, abs)
R170	30.07	-182.8	-88.6	32.2	4,872
R290	44.10	-187.3	-42.1	96.7	4,248
R600	58.12	-138.3	-0.5	152.0	3,796
R600a	58.12	-159.6	-11.6	134.7	3,640
R717	17.03	-77.7	-33.3	132.5	11,330
R744	44.01	-56.6 (A)	-78.4 (B)	31.1	7,384
R1270	42.08	-185.2	-47.7	92.4	4,665

NOTES:

(A) Freezing Point of R744 (A) condition is for 527 kPa (the triple point).

(B) Sublimation at 1 Atmosphere

8.5 Environmental Properties

Natural refrigerants have zero ozone depletion potential, a very low or zero global warming potential and a short estimated atmospheric life.

No:	Name:	Chemical Formula:	O.D.P.:	G.W.P.: 20; 100; 500 yrs	Safety Classification
R170	Ethane	$C_2 H_6$	0.0	3; **3**; 3	A3
R290	Propane	$C_3 H_8$	0.0	3; **3**; 3	A3
R600	Butane	$C_4 H_{10}$	0.0	3; **3**; 3	A3
R600a	Isobutane	$C_4 H_{10}$	0.0	3; **3**; 3	A3
R717	Ammonia	NH_3	0.0	0; **0**; 0	B2
R744	Carbon Dioxide	CO_2	0.0	1; **1**; 1	A1
R1270	Propylene	$C_3 H_6$	0.0	3; **3**; 3	A3

NOTES:

O.D.P. referenced to ozone depletion potential of CFC-11 (i.e. O.D.P. of CFC-11 = 1.0).

G.W.P. referenced to the absolute global warming potential for CO_2 using time horizons of 20, 100 and 500 years. The **bold** figures refer to the 100 year time horizon commonly used as the inventory standard.

SAFETY GROUP CLASSIFICATIONS as noted in AS 1677 part 1 are indicated by alphanumeric characters (e.g. A1, A2, B3 etc). The capital letters A or B indicate low or higher toxicity and the numeric value refers to the refrigerant's flammability (the number 1 being no flame propagation and 3 being higher flammability).

8.6 Performance of Natural Refrigerants

As all refrigerants perform differently, it is necessary to check the performance characteristic of each alternative refrigerant being considered for a particular system.

A full comparative performance analysis should be based on identical operating conditions (such as evaporating and condensing temperatures) and should include Coefficient of Performance, Compression Ratio, Mass Flow Rate, Heat Transfer and Temperature Glide. All comparisons should be based on a standard method such as that published by ASHRAE.

A variation in operating conditions will result in a meaningless comparison. Should a refrigerant be selected as a replacement refrigerant for an existing system, it will then be necessary to include the existing refrigerant in the comparative analysis.

Performance characteristics of refrigerants and blends, based on ASHRAE conditions have been included in appendix D of this guide.

8.7 What Lubricants are Suitable for Natural Refrigerants?

Hydrocarbon refrigerants possess full chemical compatibility with nearly all lubricants commonly used within refrigeration systems. Lubricants containing silicone and silicate (additives used as anti-foaming agents) are not compatible with hydrocarbon refrigerants. Particular care should be taken to ensure that replacement refrigerants and equipment manufacturer requirements are satisfied.

Compatibility of lubricants with natural refrigerants is as follows:

Traditional Lubricants	**Hydrocarbon**	**Ammonia (R717), CO_2 (R744) & Propylene (R1270)**
Mineral oil (MO)	Good suitability [1]	Good suitability
Alkyl benzene (AB)	Good suitability [1]	Limited application
Mineral Oil + Alkyl benzene	Good suitability [1]	Limited application
Poly alpha olefin (PAO)	Good suitability [1]	Good suitability
New Lubricants		
Polyol ester (POE)	Good suitability [1]	Not suitable
Poly vinyl ether (PVE)	Not suitable	Not suitable
Poly alkylene glycol (PAG)	Limited application [2]	Limited application [2]
Hydro treated mineral oil	Not suitable	Good suitability

NOTES:

[1] denotes lubricant possibly requiring basic viscosity correction.

[2] denotes lubricant that is especially critical with moisture.

8.8 What is the Effect on Metals?

Halogenated refrigerants can be used satisfactorily under normal conditions with most common metals, such as steel, cast iron, brass, copper, tin, lead and aluminium. Under more severe conditions, various metals affect such properties as hydrolysis and thermal decomposition in varying degrees. The tendency of metals to promote thermal decomposition of halogenated compounds is in the following order:
(Least decomposition) Inconel < 18-8 stainless steel < nickel < copper < 1340 steel < aluminium < bronze < brass < zinc < silver (most decomposition).
This order is only approximate and exceptions may be found for individual compounds or for special conditions. The effect of metals on hydrolysis is probably similar. Magnesium, zinc and aluminium alloys containing more than 2% magnesium are not recommended for use with halogenated compounds where even trace amounts of water may be present.

NOTES:

Do not use methyl chloride with aluminium in any form (a highly flammable gas is formed and the explosion hazard is great). Refrigerant 717 (ammonia) should never be used with copper.

8.9 Can Hydrocarbons be used in Australia?

The use of Hydrocarbons is banned or restricted for use in some Australian states. Australian Standard AS/NZ 1677.2-1998 “Refrigerating Systems Part 2: Safety Requirements for Fixed Applications”, provides for the use of Hydrocarbon refrigerants (within group A3), subject to certain conditions, building requirements and plant locations being satisfied.

The following table lists the requirements of AS/NZ 1677.2-1998 and British Standard BS:4434:1995 for Group A3 refrigerants.

Category	Example	Key Requirements
I	Hospitals, prisons, theatres, supermarkets, schools, hotels, restaurants, dwellings.	Not exceeding 1.5 kg per sealed system. Not exceeding 5.0 kg in special machinery rooms for indirect systems.
II	Offices, small shops, small restaurants, places for general manufacturing and where people work.	Not exceeding 2.5 kg per sealed system. Not exceeding 10.0 kg in special machinery rooms for indirect systems.
III	Industrial, cold stores, dairies, abattoirs, non public areas of supermarkets.	Not exceeding 10.0 kg in humanly occupied spaces. Not exceeding 25.0 kg for systems with high pressure side in special machinery rooms. No restriction of charge if all refrigerant containing parts in a special machinery room or open air.
ALL	• All associated electrical contacts shall be sealed or non-sparking. • Charge in systems below ground not to exceed 1.0 kg. • Sealed systems not exceeding 0.25 kg can be sited in any location. • For systems with charges exceeding 0.25 kg a sudden loss of refrigerant shall not raise the concentration in the room or occupied compartment above the practical limit (0.008 kg/m^3). • Piping for systems exceeding 1.5 kg must be restricted to the room containing the refrigerant.	

NOTES:

Refer AS 1677 part 2, clause 2.6 ‘Maximum Charge of Refrigerant Group A3’ for specific system requirements and limitations. Other standards to be considered are: AS 2430.1-1987 ”Classification of Hazardous Areas”; AS 1861.2-1991 “Refrigerated Packaged Air-conditioners”; AS 1861.1-1988 “Refrigerated Room Air-conditioners”; AS 1430-1986 “Household Refrigerators and Freezers”.

8.10 Service, Maintenance and Handling of Hydrocarbon Refrigerants

This section deals with practical aspects relating to the handling of hydrocarbon refrigerants and its associated machinery. All service and maintenance should be carried out by a competent person in accordance with the manufacturer’s recommendations and requirements. All competent persons should be fully versant with the hazards and safety requirements associated with hydrocarbon refrigerants.

8.11 General Approach to Handling of Hydrocarbon Refrigerants

All flammable refrigerant gases when mixed with air can form a flammable mixture. The effect of ignition of such a flammable mixture can be severe. It is therefore important that the appropriate safety requirements are observed at all times when working with flammable refrigerants.

All tools and equipment (including measuring equipment) must be checked for suitability for working with hydrocarbon equipment.

Particular attention should be paid to the selection of:

- Refrigerant recovery units.
- Refrigerant leak testing units.
- Electrical test meters.
- Refrigerant recovery cylinders.
- Portable lighting.

If the installation permits, it is recommended that the equipment is removed from its existing position to a controlled workshop environment suitable for the type of repair where the appropriate work can be safely carried out.

8.12 Safety Checks for Hydrocarbon Refrigerant Use

Check the area: Prior to commencing any service or maintenance work on systems containing hydrocarbon refrigerants it is necessary to conduct the appropriate safety checks to ensure that the risk of ignition is minimised. The following precautions should be considered the minimum required prior to commencing any work:

Work procedure: Work procedures should be planned to minimise risk of flammable gas or vapour being present while the work is being performed.

General work area: Work in confined spaces must be avoided. The area around the work space should be sectioned off. The condition within the working space should be made safe by the control of flammable materials. Instructions should be issued regarding the nature of the work being carried out.

Checking for presence of hydrocarbon refrigerant: The working space should be checked with an appropriate refrigerant detector prior to and during work to ensure that technicians are aware of a potentially flammable atmosphere. Ensure that the detection equipment being used is suitable for use with flammable refrigerants (e.g. non-sparking, adequately sealed or intrinsically safe etc.)

Presence of fire extinguisher: If any hot work is to be conducted on refrigeration equipment or any associated parts, appropriate fire extinguishing equipment (e.g. dry powder or CO_2 fire extinguisher) should be located near the work space.

No ignition sources: Work being carried out in relation to a refrigeration system involving exposing any piping or equipment that contains or has contained flammable refrigerant must use any sources of ignition in such a manner that it may lead to the risk of fire or explosion. All possible ignition sources, including cigarette smoking, must be sufficiently far away from the work space and/or site of installation, repairing, removing and disposal during which flammable refrigerant could possibly be released to the surrounding space. Should there be a need for brazing or welding, it should be undertaken in accordance with the recommendations noted elsewhere in this document. The area around the equipment should be surveyed prior to any work being undertaken to ensure that that it is safe from all flammable hazards or ignition risks.

Ventilated area: Ensure that the working space is well ventilated before any work is undertaken on any refrigerant piping or refrigerant equipment. Ventilation should safely disperse any released refrigerant and preferably expel it externally to atmosphere.

Check electrical components: Repair and maintenance to all electrical components should be included in the initial safety checks of the equipment. Ensure that power supplies are isolated prior to undertaking such an inspection and immediately repair or replace faulty electrical components. Under no circumstances should equipment operation be re-instated with faulty electrical components.

If it is essential to maintain an active power supply to the equipment during the repair activities, it is recommended that an appropriate detection system and alarm is provided in the most appropriate and critical point in the system.

Initial safety checks prior to undertaking refrigeration circuit repairs should include but not be limited to the following:

- Ensure that all capacitors are discharged to prevent possible sparking.
- Ensure that electrical power to the equipment is isolated while undertaking charging, recovering and purging of refrigeration systems.
- Check and ensure adequate and efficient earth bonding of the equipment.
- Do not alter any electrical components such that their operation or safety can compromise the safety of the system/installation.
- Check seals and sealing materials for degradation. Note that equivalent manufacturer approved seals and sealing materials should be used to replace faulty seals.
- Check and ensure that all electrical cabling and wiring is safe and not showing any wear that could contribute to potential short circuiting and sparking.

Replace all faulty components with manufacturer approved components:

Check refrigeration equipment: The following list provides an overview of checks that apply to installations employing flammable refrigerants.

- Check compliance of refrigerant charge with the latest legislated requirements. Also refer to the latest revision of Australian Standard 1677 part 2 “Refrigerating Systems Part 2: Safety Requirements for fixed applications”.
- Check ventilation provisions for adequacy and effectiveness.
- Check and verify operation of leak detection equipment.
- Check and verify refrigerant and lubricant labelling.
- Check operation of any refrigerant detection systems and alarms.
- Check refrigeration systems components and piping for potential corrosion.

- Check for excessive vibration from compressors and other moving parts such as fans.

8.13 Leak Detection of Hydrocarbon Refrigerants

Do not use any detection devices using a naked flame (including a halide torch) to search for a refrigerant leak. The following leak detection method is provided as a guide for system operating on hydrocarbon refrigerants:

- Ensure that no naked flames are present during leak detection procedures.
- Use only electronic or similar leak detection equipment without any potential ignition sources.
- Calibrate leak detection equipment to the appropriate percentage of gas concentration applicable for the installation (25% maximum concentration).
- When using fluid type leak detection methods ensure that fluids used are compatible with hydrocarbon refrigerants. Note that fluids containing chlorine may react with hydrocarbon refrigerants and corrode copper piping.
- Compatible, manufacturer approved fluorescent oil additives may be used to enhance leak detection.

It is necessary to remove all refrigerant from the system or circuit if a refrigerant leak has been located that requires brazing or welding. When system is free from refrigerant use an inert gas such as oxygen free nitrogen to purge system prior to undertaking any brazing or welding.

8.14 Decanting Hydrocarbon Refrigerant from Equipment

Familiarisation with system operation and design is necessary before decommissioning any system or decanting any refrigerant from a system or circuit. All refrigerants should be recovered safely and stored in appropriately selected and marked containers. Take a refrigerant and oil sample to ensure that both refrigerant and oil can be analysed for potential re-use of recovered refrigerant.

The following procedure is recommended to decommission a refrigeration system:

- Familiarising yourself with equipment, circuiting, system operation and operating conditions.
- Ensuring the availability of the following safety equipment prior to undertaking any works:
    - Mechanical handling equipment (if needed) to handle refrigerant containers/ cylinders.
    - Personal protective equipment.
    - A competent person to supervise remedial works.
    - Recovery equipment and cylinders that conform to the appropriate standards.
- Pumping down refrigeration system if possible.
- Isolating system from electrical power source.
- Using a manifold arrangement to decant refrigerant if a system vacuum cannot be achieved.
- Using appropriately calibrated weighing scales and place recovery cylinders on the scales prior to decanting any refrigerant.
- Not overfilling recovery cylinders (do not exceed 80% volume liquid charge).
- Not exceeding maximum cylinder working pressure.
- Ensuring that all cylinders and equipment are removed from site promptly when decanting process has been completed.
- Ensuring that all isolating valves on equipment are closed fully.
- Not re-using decanted refrigerant in another system unless it has been analysed and cleaned.

8.15 Removal and Evacuation

The following recommended procedure should be used when opening a refrigerant circuit containing flammable refrigerants:

- Remove refrigerant.
- Purge circuit with an inert gas.
- Evacuate the circuit.
- Purge circuit again with an inert gas.
- The circuit is now ready for repair such as cutting or brazing.

The entire refrigerant charge should be recovered and stored in correct recovery cylinders. Once the system is free from flammable refrigerant it is necessary to repeatedly flush the system with an inert gas such as oxygen free nitrogen until no flammable gas is present inside the circuit. Do not use compressed air or oxygen to flush refrigerant circuits.

Triple flushing procedures should be conducted as follows:

Step 1	break vacuum in circuit/system with oxygen free nitrogen. Continue to pressurise system with oxygen free nitrogen until an appropriate working pressure is reached.
Step 2	vent inert gas to atmosphere and repeat step 1.
Steps 1 and 2	should be repeated three times or until satisfied that no flammable refrigerant is present inside the circuit.

Ensure that an inert gas is used to bleed through the circuit/system while any brazing or welding activities are taking place.

Ensure that bleed outlets and evacuation pumps are sufficiently far away from any potential ignition sources and that the space is adequately vented.

8.16 What Considerations should be made in the Selection and Application of a Hydrocarbon Refrigerant?

- ***Use hydrocarbons only with the written approval of the respective equipment manufacturer;***
- ***Service and installation personnel should be suitably trained;***
- ***Work should be carried out on appropriately approved premises;***
- ***Satisfy the requirements of all relevant and applicable Australian Standards;***
- ***Comply with the legislative requirements of the respective state;***
- ***Comply with the requirements of the respective local governing authorities (i.e. Department of Minerals and Energy, etc.);***
- ***All refrigerants and lubricant used in any system must be identified with permanent labelling;***
- ***Use only hydrocarbon refrigerant having an ASHRAE or ISO "R" number***

8.17 Safety Design and Construction

The use of hydrocarbons is banned or restricted for use in some Australian states. Australian Standard AS/NZ 1677.2-1998 “Refrigerating Systems Part 2: Safety Requirements for fixed applications”, provides for the use of Hydrocarbon refrigerants (within group A3), subject to certain conditions.

References

- ANZECC "Revised Strategy for Ozone Protection in Australia 1994".
- 1993 ASHRAE Hand Book of Fundamentals.
- ASHRAE Standard 34 – 1992 ‘Number Designation and safety classification of refrigerants’ including amendments up to and including May 28, 1996.
- Product literature provided by Honeywell (formally known as Allied Signal Chemicals).
- Product literature provided by Ineus (formally known as ICI Klea).
- Product literature provided by Rhone-Poulenc.
- Product literature provided by Atofina (formally known as Elf Atochem).
- Product literature provided by DuPont Fluorochemicals.
- International Institute of Refrigeration, International Journal of Refrigeration Volume 19, Number 8 1996, Review paper “Working fluids for mechanical refrigeration - Invited paper presented at the 19th International Congress of Refrigeration, The Hague, August 1995”.
- International Institute of Refrigeration, Applications for Natural Refrigerants, Refrigeration Science and Technology Proceedings, 1996-3, “Experiences with Hydrocarbon Blends in the UK Market, by T.J. Ritter”.
- International Institute of Refrigeration, 12th Informatory Note of the IIR on Fluorocarbons and Refrigeration, Fluorocarbons and global warming, dated July 1997.
- International Climate Change Partnership - results of Kyoto Meeting, dated 18 December 1997.
- Climate Change: More than just Carbon Dioxide by Ministry for the Environment, N.Z.
- Refrigeration and Air Conditioning Industry Registration Board, Training Guide.
- Bitzer International ‘Refrigerants Report 8’.
- HPAC Engineering ‘New Physical, Safety & Environmental Data for Refrigerants’ dated August 1999.
- ACRIB (Air Conditioning and Refrigeration Industry Board) Guidelines for the use of Hydrocarbon Refrigerants in Static Refrigeration and Air conditioning Systems, published February 2001.
- Kyoto Protocol to the United Nations Framework Convention on Climate Change.
- Montreal Protocol on Substances that Deplete the Ozone Layer.
- NIST Standard Reference Data Base 23 ‘Thermodynamic and Transport Properties of Refrigerants and Refrigerant Mixtures – REFPROP, version 6.0.
- NIST Standard Reference Data Base 49 ‘Vapour Compression Design Program – Cycle_D’ version 2.2.
- Ozone Protection Act 1989.

Appendix A – Terminology

AZEOTROPIC REFRIGERANTS:	Blends comprising multiple components of different volatilities that, when used in refrigeration cycles, do not change volumetric composition or saturation temperatures as they evaporate (boil) or condense at constant pressure.
BOILING POINT:	The temperature at which a fluid will change from liquid to a gas. The boiling point will depend on the pressure exerted on the surface of the liquid.
CONDENSING PRESSURE:	The condensing pressure is the saturation pressure corresponding to the temperature of the liquid-vapour mixture in the condenser.
CRITICAL TEMPERATURE:	The temperature at which the density of the liquid and the density of the vapour become the same. At this point the meniscus at the liquid-vapour boundaries disappears. The critical temperature is different for every gas.
CRITICAL PRESSURE:	The pressure is the lowest pressure at which a substance can exist in the liquid state at its critical temperature; that is, it is the saturation pressure at the critical temperature.
COMPRESSION RATIO:	The ratio of the absolute discharge pressure to the absolute suction.
COEFFICIENT OF PERFORMANCE:	The ratio of refrigeration provided (in kilowatts) to energy input (in kilowatts). For example, if a refrigeration circuit consumes 1 kW of power and provides 5 kW of cooling it has a COP of 5.0.
EVAPORATOR PRESSURE:	The pressure of the refrigerant gas leaving the evaporator and being drawn to the suction inlet to the compressor.
FREEZING POINT:	The temperature of a substance at which freezing occurs.

NET REFRIGERATING EFFECT:

The available refrigerating capacity (in evaporator) per kilogram of refrigerant circulating for the nominated conditions.

REFRIGERANT CIRCULATED:

The amount of refrigerant circulated per second per kilowatt of refrigeration.

TEMPERATURE GLIDE:

A single component refrigerant, such as CFC-12 or HFC-134a, boils at a constant temperature for a given pressure.

Mixtures containing more than one component, such as R-500 and R502 (ASHRAE 500 series refrigerants), that boil at a constant temperature are called azeotropes.

Near-Azeotropic and non-Azeotropic mixtures (ASHRAE R400 series refrigerants) behave somewhat differently. Their compositions and boiling points do change as the material boils. This is because the components of the blend have different boiling points and hence boil off at different rates from each other.

When a non-Azeotropic or Zeotropic mixture boils as it passes through the evaporator, the vapour given off is richer in the more volatile (lower boiling point) component.

The liquid therefore tends to become richer in the less volatile (higher boiling point) component and boils at a higher temperature.

This increase in boiling temperature during the evaporation process is called temperature glide. The reverse applies to condensation. The mixture is at its original composition when fully evaporated or fully condensed. In simple terms, the vapour temperature leaving an evaporator will be higher than the liquid temperature entering the evaporator. This is reversed in the condensing process.

ZEOTROPIC REFRIGERANTS:

Blends comprising multiple components of different volatilities that, when used in refrigeration cycles, change volumetric composition and saturation temperatures as they evaporate (boil) or condense at constant pressure.

Appendix B – Refrigerant Development

ALTERNATIVE REFRIGERANTS

Transitional and Retrofit Refrigerant

Medium and Long Term Refrigerant

HCFC/HFC
Partly Chlorinated

Man-Made HFC
Chlorine Free
Halogenated

Natural
Halogen Free

ISO#	Trade Name	Manufacturer	Ref.	CFC	HCFC	HFC	HC/ Natural	Replaces
R11	-			X				
R12	-			X				
R22	-				X			R502
R113	-			X				
R114	-			X				
R123	-				X			R11
R124	-		3		X			R114
R125	-					X		-
R134a	-					X		**R12/R500**
R170	Ethane		1				X	**R503**
R290	Propane		1, 3				X	**R22/R502**
R401A	MP39	DuPont			X			R12
R401B	MP66	DuPont			X			R12
R401C	MP52	DuPont			X			R12
R402A	HP80	DuPont			X			R502
R402B	HP81	DuPont			X			R502
R403A	Isceon 69S	Rhodia			X			R502
R403B	Isceon 69L	Rhodia			X			R502
R404A	HP62 FX70	DuPont Atofina				X		**R502**

ISO#	Trade Name	Manufacturer	Ref.	CFC	HCFC	HFC	HC/ Natural	Replaces
R405A	G2015	Greencool			X			R12
R406A	GHG-HP	Indianapolis			X			R12
R407A	Klea60	ICI				X		**R12/R502**
R407B	Klea61	ICI				X		**R502**
R407C	Klea66	ICI				X		**R22**
R408A	FX10	Atofina			X			R502
R409A	FX56	Atofina			X			R12
R409B	FX57	Atofina			X			R12
R410A	Suva9100 AZ20	Dupont Honeywell	3			X		**R22**
R411A	G2018A	Greencool			X			R22
R411B	G2018B	Greencool			X			R502
R412A	TP5R	Arcton			X			R500
R413A	Isceon 49	Rhodia				X		R12
R414A	GHG-X4	Indianapolis						
R416A	FR-12				X			R12
R417A	Isceon 59	Rhodia				X		**R22**
R500	-			X				CFC
R502	-			X				CFC
R507	AZ50	Honeywell				X		**R502**
R509A	TP5R2	Arcton			X			R502
R600	Butane		1				X	**R12**
R600a	Isobutane		1, 3				X	**R12/R114**
R717	Ammonia		1, 2, 4				X	**R502**
R744	Carbon dioxide		1, 3				X	**Various**
R1270	Propylene		1				X	R22

NOTES:

1. denotes flammable refrigerant
2. denotes toxic refrigerant
3. denotes refrigerant with large deviation in refrigerant capacity and pressure compared to the refrigerant it replaces
4. denotes refrigerant not compatible with copper

Appendix C – Fluorinated Refrigerants Performance Tables

Condition A: 258 K (-15°C) evaporation and 303 K (30°C) condensing

No:	Evaporator Pressure: (kPa)	Condensing Pressure: (kPa)	Comp. Ratio:	Net Refrigerating Effect: (kJ/kg)	Refrigerant Circulated: (kg/s)	Coeff. Of Perform. (Cooling)	Temp Glide: (°C)
CFC's:							
R11	20	126	6.30	155.89	0.00641	5.03	0
R12	182	744	4.09	116.94	0.00855	4.70	0
R113	7	54	7.71	122.53	0.00816	4.87	0
R114	47	252	5.36	99.42	0.01006	4.68	0
R500	215	881	4.10	139.28	0.00718	4.65	0
R502	344	1,317	3.83	106.00	0.00943	4.38	0
HCFC's:							
R22	296	1,192	4.03	162.54	0.00615	4.66	0
R123	16	110	6.88	142.22	0.00703	4.90	0
R124	89	445	5.00	117.75	0.00849	4.64	0
R401A	183	931	5.09	156.03	0.00641	4.15	4.1/4.3
R401B	199	978	4.91	157.31	0.00636	4.20	3.7/3.8
R401C	148	808	5.46	149.11	0.00671	4.07	4.6/5.3
R402A	386	1,534	3.97	112.91	0.00886	4.16	0.9/1.0
R402B	352	1,432	4.07	130.74	0.00765	4.29	1.2/1.3
R403A	343	1,350	3.94	N.A.	N.A.	4.44	2.0/1.6
R403B	380	1,448	3.81	N.A.	N.A.	4.26	1.1/0.6
R405A	153	869	5.68	128.25	0.00797	3.83	6.0/6.7
R406A	146	849	5.82	168.57	0.00593	3.85	6.9/8.1
R408A	349	1,367	3.92	141.54	0.00707	4.43	0.3/0.3
R409A	174	951	5.47	150.97	0.00662	3.92	6.2/6.5
R409B	191	995	5.21	150.32	0.00665	4.00	5.4/5.5
R411A	259	1,127	4.35	173.80	0.00575	4.46	1.7/1.6
R411B	291	1,200	4.12	167.93	0.00595	4.54	0.8/0.7
R412A	175	801	4.58	N.A.	N.A.	4.70	7.8/8.7
R509A	380	1,430	3.76	N.A.	N.A.	4.12	0
HFC's:							
R125	406	1,567	3.86	85.17	0.00117	3.987	0
R134a	164	770	4.70	147.91	0.00676	4.61	0

No:	Evaporator Pressure: (kPa)	Condensing Pressure: (kPa)	Comp. Ratio:	Net Refrigerating Effect: (kJ/kg)	Refrigerant Circulated: (kg/s)	Coeff. Of Perform. (Cooling)	Temp Glide: (°C)
R404A	364	1,433	3.94	113.49	0.00881	4.16	0.5/0.4
R407A	287	1,426	4.97	144.22	0.00693	3.89	4.3/4.7
R407B	333	1,503	4.51	114.73	0.00872	3.91	2.8/2.9
R407C	264	1,356	5.14	156.89	0.00637	3.91	4.6/5.2
R410A	480	1,883	3.92	167.57	0.00598	4.40	0.1/0.1
R413A	178	830	4.66	N.A.	N.A.	4.70	7.8/8.7
R417A	220	1,082	4.92	122.42	0.00817	3.98	2.9/3.7
R507A	381	1,466	3.85	109.95	0.00910	4.18	0

Condition B: 200 K (-73°C) evaporation and 238 K (-35°C) condensing

No:	Evaporator Pressure: (kPa)	Condensing Pressure: (kPa)	Comp. Ratio:	Net Refrigerating Effect: (kJ/kg)	Refrigerant Circulated: (kg/s)	Coeff. Of Perform. (Cooling)	Temp Glide: (°C)
HCFC's:							
R22	17	132	7.76	211.86	0.00472	4.52	0
R411A	13	125	9.62	225.39	0.00444	4.16	2.5/2.4
HFC's:							
R125	25	185	7.40	134.75	0.00742	4.47	0
R407C	12	152	12.67	214.62	0.00466	3.65	6.5/6.9
R410A	30	220	7.33	236.95	0.00422	4.49	0/0.1
R417A	10	116	11.60	172.51	0.00580	3.90	4.3/5.1

Condition C: 213 K (-60°C) evaporation and 258 K (-15°C) condensing

No:	Evaporator Pressure: (kPa)	Condensing Pressure: (kPa)	Comp. Ratio:	Net Refrigerating Effect: (kJ/kg)	Refrigerant Circulated: (kg/s)	Coeff. Of Perform. (Cooling)	Temp Glide: (°C)
CFC's							
R12	23	182	7.91	138.47	0.00722	4.03	0
HCFC's:							
R22	38	296	7.79	195.90	0.00510	3.98	0
R401A	19	225	11.84	186.88	0.00535	3.44	5.2/5.2
R401B	21	238	11.33	188.6	0.00530	3.48	4.7/4.6

No:	Evaporator Pressure: (kPa)	Condensing Pressure: (kPa)	Comp. Ratio:	Net Refrigerating Effect: (kJ/kg)	Refrigerant Circulated: (kg/s)	Coeff. Of Perform. (Cooling)	Temp Glide: (°C)
R401C	14	191	13.64	178.32	0.00561	3.37	5.7/6.4
R401A	19	225	11.84	186.88	0.00535	3.44	5.2/5.2
R401B	21	238	11.33	188.6	0.00530	3.48	4.7/4.6
R401C	14	191	13.64	178.32	0.00561	3.37	5.7/6.4
R409A	18	234	13.00	180.14	0.00555	3.24	7.3/7.6
R409B	20	245	12.25	179.93	0.00556	3.31	6.5/6.5
R411A	31	280	9.03	208.53	0.00480	3.72	2.3/2.1
HFC's:							
R125	55	406	7.38	118.70	0.00842	3.79	0
R134a	16	164	10.25	181.17	0.00552	3.99	0
R407C	28	339	12.11	195.79	0.00511	3.31	5.9/6.5
R413A	N.A.	N.A.	N.A.	N.A.	N.A.	3.64	N.A.
R417A	23	264	11.48	155.49	0.00643	3.47	3.8/4.7

Condition D: 233 K (-40^{o}C) evaporation and 293 K (20^{o}C) condensing

No:	Evaporator Pressure: (kPa)	Condensing Pressure: (kPa)	Comp. Ratio:	Net Refrigerating Effect: (kJ/kg)	Refrigerant Circulated: (kg/s)	Coeff. Of Perform. (Cooling)	Temp Glide: (°C)
CFC's:							
R12	64	566	8.84	115.04	0.00869	3.02	0
R500	76	671	8.83	138.35	0.00722	3.00	0/0.1
HCFC's:							
R22	105	910	8.67	164.07	0.00609	3.01	0
R401A	59	708	12.00	155.39	0.00644	2.70	4.3/4.5
R401B	65	744	11.45	157.03	0.00637	2.73	3.9/4.0
R401C	46	611	13.28	147.54	0.00678	2.66	4.6/5.6
R405A	47	660	14.04	126.14	0.00793	2.50	6.2/7.0
R406A	46	647	14.07	167.15	0.00598	2.56	6.8/8.4
R409A	55	725	13.18	150.13	0.00666	2.58	6.4/6.8
R409B	62	759	12.24	149.80	0.00668	2.62	5.7/5.7
R411A	89	860	9.66	174.94	0.00572	2.88	1.9/1.7
R412A	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
HFC's:							

R125	149	1,205	8.09	85.47	0.01170	2.56	0
R134a	51	572	11.22	146.54	0.00682	2.95	0
R407A	95	1,091	11.48	145.29	0.00688	2.55	4.5/5.0
No:	**Evaporator Pressure:** (kPa)	**Condensing Pressure:** (kPa)	**Comp. Ratio:**	**Net Refrigerating Effect:** (kJ/kg)	**Refrigerant Circulated:** (kg/s)	**Coeff. Of Perform.** (Cooling)	**Temp Glide:** (°C)
R407B	114	1,153	10.11	115.39	0.00867	2.54	3.1/3.1
R407C	86	1,035	12.03	157.98	0.00633	2.56	4.7/5.6
R410A	176	1,443	8.20	172.99	0.00578	2.86	0/0.1
R413A	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A
R417A	72	823	11.43	121.19	0.00825	2.58	2.8/4.0

Condition E: 250 K (-23°C) evaporation and 310 K (37°C) condensing

No:	**Evaporator Pressure:** (kPa)	**Condensing Pressure:** (kPa)	**Comp. Ratio:**	**Net Refrigerating Effect:** (kJ/kg)	**Refrigerant Circulated:** (kg/s)	**Coeff. Of Perform.** (Cooling)	**Temp Glide:** (°C)
CFC's:							
R11	14	159	11.36	145.59	0.00687	3.46	0
R12	134	890	6.64	106.11	0.00942	3.15	0
R22	218	1,424	6.53	150.09	0.00666	3.14	0
R114	32	310	9.69	87.28	0.01146	1.49	0
R502	257	1,565	6.09	93.58	0.01069	2.85	0
HCFC's:							
R123	10	140	14.00	130.27	0.00767	3.33	0
R124	62	546	8.81	104.90	0.00953	3.07	0
R401A	131	1,117	8.53	142.56	0.00701	2.85	3.9/4.1
R401B	143	1,172	8.20	144.00	0.00684	2.88	3.5/3.6
R401C	105	970	9.24	135.44	0.00738	2.80	4.2/5.1
R402A	287	1,820	6.34	98.89	0.01011	2.71	0.8/0.9
R402B	261	1,701	6.52	117.19	0.00853	2.84	1.1/1.2
R403A	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
R403B	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
R405A	108	1,041	9.64	114.78	0.00871	2.62	5.6/6.4
R406A	104	1,016	9.77	154.49	0.00647	2.70	6.4/7.9
R408A	259	1,626	6.28	127.04	0.00787	2.92	0.3/0.2
R409A	124	1,138	9.18	137.99	0.00725	2.72	5.9/6.3

No:	**Evaporator Pressure:** (kPa)	**Condensing Pressure:** (kPa)	**Comp. Ratio:**	**Net Refrigerating Effect:** (kJ/kg)	**Refrigerant Circulated:** (kg/s)	**Coeff. Of Perform.** (Cooling)	**Temp Glide:** (°C)
R409B	137	1,190	8.69	137.46	0.00728	2.76	5.2/5.3
R411A	189	1,347	7.13	160.41	0.00623	3.03	1.6/1.5
R411B	214	1,432	6.69	154.83	0.00646	3.07	0.8/0.6

No:	Evaporator Pressure: (kPa)	Condensing Pressure: (kPa)	Comp. Ratio:	Net Refrigerating Effect: (kJ/kg)	Refrigerant Circulated: (kg/s)	Coeff. Of Perform. (Cooling)	Temp Glide: (°C)
HFC's:							
R125	302	1,865	6.18	70.62	0.01416	2.46	0
R134a	116	937	8.08	132.74	0.00753	3.05	0
R404A	270	1,706	6.32	97.84	0.01022	2.65	0.5/0.4
R407A	207	1,702	8.22	128.96	0.00775	2.62	3.9/4.4
R407B	243	1,792	7.37	99.85	0.01002	2.55	2.6/2.7
R407C	190	1,620	8.53	141.47	0.00707	2.66	4.2/5.0
R410A	357	2,246	6.29	151.93	0.00658	2.90	0/0.1
R413A	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
R417A	158	1,297	8.21	107.16	0.00933	2.63	2.5/3.5
R507	284	1,744	6.14	94.36	0.01060	2.65	0

Condition F: 266 K (-7°C) evaporation and 300 K (23°C) condensing

No:	Evaporator Pressure: (kPa)	Condensing Pressure: (kPa)	Comp. Ratio:	Net Refrigerating Effect: (kJ/kg)	Refrigerant Circulated: (kg/s)	Coeff. Of Perform. (Cooling)	Temp Glide: (°C)
CFC's:							
R11	30	99	3.30	166.17	0.00601	8.16	0
R12	243	616	2.53	127.57	0.00784	7.79	0
R500	287	729	2.54	151.83	0.00659	7.72	0
R502	453	1,100	2.43	118.00	0.00847	7.42	0
HCFC's:							
R22	394	989	2.51	174.60	0.00572	7.72	0
R114	66	201	3.05	111.56	0.00896	2.31	0
R123	24	85	3.54	154.14	0.00649	8.04	0
R124	124	360	2.90	130.45	0.00767	7.75	0
R401A	250	770	3.08	169.19	0.00591	6.57	4.3/4.5
R401B	270	810	3.00	170.30	0.00587	6.68	3.9/3.9
R401C	204	666	3.26	162.52	0.00615	6.39	5.0/5.5
R402A	509	1,283	2.52	126.41	0.00791	7.01	1.1/1.1
R402B	466	1,196	2.57	143.82	0.00695	7.09	1.3/1.4
R403A	N.A.	N.A.	N.A	N.A	N.A.	N.A.	N.A.

No:	Evaporator Pressure: (kPa)	Condensing Pressure: (kPa)	Comp. Ratio:	Net Refrigerating Effect: (kJ/kg)	Refrigerant Circulated: (kg/s)	Coeff. Of Perform. (Cooling)	Temp Glide: (°C)
R403B	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
R405A	211	718	3.40	141.48	0.00707	6.00	6.5/6.9
R406A	200	703	3.52	182.38	0.00548	5.90	7.5/8.3
R408A	461	1,139	2.47	155.52	0.00643	7.42	0.3/0.3
R409A	238	788	3.31	163.67	0.00611	6.08	6.5/6.7
R409B	260	825	3.17	162.88	0.00614	6.26	5.7/5.7
R411A	347	935	2.69	186.80	0.00535	7.24	1.8/1.6
R411B	388	997	2.57	180.62	0.00554	7.47	0.8/0.7
HFC's:							
R125	535	1,305	2.44	99.14	0.01009	7.02	0
R134a	226	627	2.77	162.76	0.00614	7.70	0
R404A	481	1,195	2.48	128.54	0.00778	7.12	0.5/0.4
R407A	389	1,185	3.05	158.96	0.00629	6.24	4.7/4.9
R407B	446	1,251	2.80	129.08	0.00775	6.47	3.0/3.0
R407C	358	1,125	3.14	171.81	0.00582	6.20	5.1/5.5
R410A	634	1,566	2.47	182.38	0.00548	7.40	0.1/0.1
R413A	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
R417A	298	896	3.01	137.31	0.00728	6.49	3.4/3.9
R507	502	1,222	2.43	124.93	0.00800	7.21	0

Condition G: 277 K (4^{o}C) evaporation and 310 K (37^{o}C) condensing

No:	Evaporator Pressure: (kPa)	Condensing Pressure: (kPa)	Comp. Ratio:	Net Refrigerating Effect: (kJ/kg)	Refrigerant Circulated: (kg/s)	Coeff. Of Perform. (Cooling)	Temp Glide: (°C)
CFC's:							
R11	48	159	3.31	159.41	0.00627	7.63	0
R12	351	890	2.53	118.44	0.00844	7.14	0
R500	414	1,055	2.55	139.86	0.00715	7.05	0
R502	642	1,565	2.44	105.42	0.00949	6.65	0
HCFC's:							
R22	566	1,424	2.52	160.81	0.00622	7.06	0
R114	103	310	3.01	103.21	0.00969	7.14	0
R123	39	140	3.59	146.36	0.00683	7.47	0

No:	Evaporator Pressure: (kPa)	Condensing Pressure: (kPa)	Comp. Ratio:	Net Refrigerating Effect: (kJ/kg)	Refrigerant Circulated: (kg/s)	Coeff. Of Perform. (Cooling)	Temp Glide: (°C)
R124	189	546	2.89	120.80	0.00828	7.11	0
R401A	371	1,117	3.01	156.37	0.00640	6.15	4.0/4.1
R401B	399	1,172	2.94	157.31	0.00636	6.24	3.6/3.6
R401C	305	970	3.18	150.35	0.00665	6.01	4.6/5.1
R402A	724	1,820	2.51	111.53	0.00897	6.27	0.9/0.9
R402B	665	1,701	2.56	129.25	0.00774	6.44	1.2/1.2
R403A	N.A.	N.A.	N.A.	N.A	N.A.	N.A.	N.A.
R403B	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
R405A	316	1,041	3.29	129.98	0.00769	5.64	5.9/6.4
R406A	299	1,016	3.40	169.72	0.00589	5.58	7.1/7.9
R408A	656	1,626	2.48	139.66	0.00716	6.69	0.2/0.2
R409A	353	1,138	3.22	151.52	0.00660	5.73	6.1/6.3
R409B	384	1,190	3.10	150.55	0.00664	5.88	5.3/5.3
R411A	504	1,347	2.67	172.44	0.00580	6.70	1.6/1.5
R411B	558	1,432	2.57	166.26	0.00601	6.87	0.7/0.6
HFC's:							
R125	760	1,865	2.45	84.35	0.01186	6.07	0
R134a	338	937	2.77	148.97	0.00671	7.03	0
R404A	685	1,706	2.49	112.19	0.00891	6.30	0.4/0.4
R407A	571	1,702	2.98	142.77	0.00700	5.76	4.2/4.4
R407B	648	1,792	2.77	113.63	0.00880	5.85	2.7/2.7
R407C	529	1,620	3.06	155.47	0.00643	5.75	4.6/5.0
R410A	903	2,246	2.49	161.84	0.00618	6.59	0.1/0.1
R413A	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
R417A	441	1,297	2.94	123.24	0.00811	5.95	3.0/3.5
R507	712	1,744	2.45	108.55	0.00921	6.34	0

NOTES:

- Performance details are calculated in accordance with the requirements for ASHRAE 2001 Book of Fundamentals Chapter 19 and are based on the temperatures and conditions noted for each table.
- All values noted in the aforementioned tables are refrigerant cycle efficiencies using 100% compressor volumetric, compressor motor and compressor isentropic efficiencies. No allowances have been made for sub cooling liquid or superheating suction refrigerant gas temperatures.
- The tables include refrigerants recommended for the noted operating conditions.
- All pressures note in the above tables are gauge pressures measured for vapour refrigerant conditions.
- Temperature glide values for zeotropic blends (R400 series refrigerants) include the evaporating glide as the first value and the condensing glide as the second value.

- N.A. Denotes information not available at the time of publication.

Appendix D – Natural Refrigerants Performance Tables

Condition A: 258 K (-15°C) evaporation and 303 K (30°C) condensing

No:	Evaporator Pressure: (kPa)	Condensing Pressure: (kPa)	Comp. Ratio:	Net Refrigerating Effect: (kJ/kg)	Refrigerant Circulated: (kg/s)	Coeff. Of Perform.	Temp Glide: (°C)
R170	1,630	4,653	2.85	160.51	0.00623	2.72	0.0
R290	292	1,079	3.70	278.01	0.00360	4.55	0.0
R600	56	284	5.07	292.08	0.00342	4.77	0.0
R600a	89	404	4.54	263.74	0.00379	4.67	0.0
R717	236	1,167	4.94	1,102.61	0.00091	4.77	0.0
R744	2,287	7,205	3.15	131.59	0.00760	2.69	0.0
R1270	364	1,308	3.59	286.26	0.00349	4.55	0.0

Condition B: 183 K (-90°C) evaporation and 233 K (-40°C) condensing

No:	Evaporator Pressure: (kPa)	Condensing Pressure: (kPa)	Comp. Ratio:	Net Refrigerating Effect: (kJ/kg)	Refrigerant Circulated: (kg/s)	Coeff. Of Perform. (cooling)
R170	94	778	8.27	362.61	0.00275	2.87

Condition C: 200 K (-73°C) evaporation and 238 K (-35°C) condensing

No:	Evaporator Pressure: (kPa)	Condensing Pressure: (kPa)	Comp. Ratio:	Net Refrigerating Effect: (kJ/kg)	Refrigerant Circulated: (kg/s)	Coeff. Of Perform. (Cooling)
R170	219	913	4.16	366.68	0.00273	4.35

Condition D: 213 K (-60°C) evaporation and 258 K (-15°C) condensing

No:	Evaporator Pressure: (kPa)	Condensing Pressure: (kPa)	Comp. Ratio:	Net Refrigerating Effect: (kJ/kg)	Refrigerant Circulated: (kg/s)	Coeff. Of Perform. (Cooling)
R170	379	1,630	4.30	320.00	0.00312	3.64
R290	43	292	6.79	340.99	0.00293	4.00
R717	22	236	10.73	1,242.32	0.00080	3.78

Condition E: 233 K (-40°C) evaporation and 293 K (20°C) condensing

No:	Evaporator Pressure: (kPa)	Condensing Pressure: (kPa)	Comp. Ratio:	Net Refrigerating Effect: (kJ/kg)	Refrigerant Circulated: (kg/s)	Coeff. Of Perform. (Cooling)
R290	111	836	7.53	276.05	0.00362	2.94
R717	72	858	11.92	1,113.98	0.00090	2.99
R744	1,004	5,722	5.70	179.55	0.00557	2.21

Condition F: 250 K (-23°C) evaporation and 310 K (37°C) condensing

No:	Evaporator Pressure: (kPa)	Condensing Pressure: (kPa)	Comp. Ratio:	Net Refrigerating Effect: (KJ/kg)	Refrigerant Circulated: (kg/s)	Coeff. Of Perform. (Cooling)
R717	166	1,430	8.61	1,057.63	0.00095	3.24

Condition G: 266 K (-7°C) evaporation and 300 K (23°C) condensing

No:	Evaporator Pressure: (kPa)	Condensing Pressure: (kPa)	Comp. Ratio:	Net Refrigerating Effect: (kJ/kg)	Refrigerant Circulated: (kg/s)	Coeff. Of Perform. (Cooling)
R290	381	904	2.37	306.55	0.00326	7.61
R600	79	230	2.91	320.63	0.00312	7.90
R600a	121	330	2.73	291.68	0.00343	7.79
R717	328	943	2.88	1,146.24	0.00087	7.85

Condition H: 277 K (4°C) evaporation and 310 K (37°C) condensing

No:	Evaporator Pressure: (kPa)	Condensing Pressure: (kPa)	Comp. Ratio:	Net Refrigerating Effect: (kJ/kg)	Refrigerant Circulated: (kg/s)	Coeff. Of Perform. (Cooling)
R290	535	1,277	2.39	279.64	0.00358	6.90
R600	120	349	2.91	301.49	0.00332	7.30
R600a	180	490	2.72	271.48	0.00368	7.16
R717	498	1,430	2.87	1,090.53	0.00092	7.32

NOTES:

Performance details are calculated in accordance with the requirements for ASHRAE Book of Fundamentals 2001 Chapter 19 and are based on the temperatures and conditions noted for each table.

All values noted in the aforementioned tables are refrigerant cycle efficiencies using 100% compressor and motor efficiencies.

The tables include refrigerants recommended for the noted operating conditions.

All pressures note in the above tables are gauge pressures measured for vapour refrigerant conditions.

N.A. Denotes information not available at the time of publication.

The Challenge

The problems associated with stratospheric ozone depletion and global warming have and will continue to be the driving force behind the radical changes in the refrigeration industry worldwide. This is especially true for the areas of commercial refrigeration and air conditioning systems with their wide range of applications. These changing times require system designers, technicians and operators/owners to keep abreast of ongoing developments and technology affecting the longevity of our industry.

Stakeholders in the refrigeration and air conditioning industry now face the challenge and opportunity to address the requirements of the *Montreal Protocol* and *Kyoto Protocol* in a professional manner by selecting a low or zero ozone depleting refrigerant with a minimal global warming potential, without compromising system reliability, energy consumption or safety. All new refrigerants noted in this guide are supported by a broad base of service capabilities and experience in Australia. The challenge therefore is to develop acceptable plans that lead directly to environmentally acceptable long-term solutions, within time frames that are consistent with both international and Australian legislative requirements.

As this document considers a very dynamic subject which will change with the development of new refrigerants and technologies, we invite those interested parties or persons to contribute their comments for consideration in future issues of this guide. Your comments can be forwarded to AIRAH.

For further information or additional copies:

THE AUSTRALIAN INSTITUTE OF REFRIGERATION,

AIR CONDITIONING & HEATING INC.

ABN 81 004 082 928

Level 7, 1 Elizabeth Street • Melbourne • VIC • 3000

Tel.: (03) 9614 8868 • Fax.: (03) 9614 8949

www.airah.org.au