IN FROM THE COLD

Strategies to increase the energy efficiency of non-domestic refrigeration in Australia & New Zealand

BACKGROUND TECHNICAL REPORT VOLUME 2

30 October 2009

This paper has been prepared for the Equipment Energy Efficiency Committee under the auspices of the Australian and New Zealand Ministerial Council for Energy.

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Foreword

This report is one of two technical support documents associated with ***In from the Cold***, the 10 year strategic plan to promote energy efficiency in the non-domestic refrigeration sector in Australia and New Zealand.

Volume 1 of the technical support documents deals with refrigerated cabinets, including display cabinets.

Volume 2 of the technical support documents deals with other sectors and technologies in the non-domestic refrigeration sector.

Contents

Table of Figures

Table of Tables

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Glossary

Alternative refrigerants:	Alternative to those commonly used in the Commercial Refrigeration Industry e.g. (R744-CO2 and R717-ammonia).
Ammonia refrigerant:	Refrigerant - R717 (NH_3). Ammonia's thermodynamic properties, make it very effective as a refrigerant, and is widely used in industrial refrigeration applications because of its high energy efficiency and relatively low cost. Ammonia is used less frequently in commercial applications, such as in grocery store freezer cases and refrigerated displays due to its toxicity.
ARCTICK:	Australian Refrigeration Council's authorised business symbol.
Carbon Pollution Reduction Scheme:	The CPRS is a proposed Australian Government initiative which places a limit, or cap, on the amount of carbon pollution industry in Australia can emit. It will require the largest businesses (approximately the top 1,000) to buy a 'pollution permit' for each tonne of carbon they emit.
Cascade refrigeration system:	A cascade system is made up of two separate but connected refrigeration systems, each of which have a primary refrigerant where refrigerants work in concert to reach the desired temperature. Cascade system in operation today in Australia are R404A/R744(CO2); R134a/R744 and R717(ammonia)/R744.
CFCs (R12 and R502):	Refrigerants that are in the chlorofluorocarbons group and known as CFCs, are now in a process of complete elimination from use, as it is both illegal to release into the atmosphere, and removal from existing systems must be undertaken in an approved manner for disposal in the event of system decommissioning. Alternative approved products are available as substitutes.
CO_2 refrigerant R 744:	A widely used Industrial and Process refrigerant with high thermodynamic properties suitable for refrigeration use, but due to its high pressure operating levels in typical commercial refrigeration ranges, less applications are in common use. More systems are now being designed as components such as compressors and other line equipment are available.
Cold food chain:	The cold food chain is part of the food value chain, which involves transport, storage, distribution and retailing of chilled and frozen foods.
Compressor:	A device in the refrigeration circuit which compresses refrigerant vapour, and circulates that refrigerant through to its phases of condensation and evaporation, in order to produce refrigeration effect. The compressor is available in many forms such as piston, scroll, or screw.

Compressor rack:	The machine assembly which accommodates the main high pressure components of a refrigeration circuit in a single structure, allowing off site connection to associated pipe work and vessels.
EN:	European Standard denotation.
EN ISO:	European Standard based on International Standard.
HCFCs refrigerant (R22):	A refrigerant which has predominant use in the air conditioning industry, and is being phased out. As components become available, particularly compressors, its general replacement may be R410A.
Heat transfer fluids:	Any fluid which is used to transport its heat content to another location within a process, for either removal or adding to, or storage for subsequent use.
HFC refrigerant:	HFCs (R404A/R507 and R134a) refrigerants used as replacements for those in the now illegal CFC range.
Integral RDCs:	Refrigerated display cabinet with its refrigerating machinery contained integrally within the structure.
K-value:	The k-value, or heat transfer coefficient, is the measured value of the heat flow which is transferred through an area of 1 m^2 at a temperature difference of 1 K. The units of measure are watts per square meter per temperature difference (W/m^2K). K-value = energy / (area x temperature difference x time).
R-value:	Is a measure of thermal resistance, commonly used in the building and construction industry. Under uniform conditions it is the ratio of the temperature difference across an insulator and the heat flux (heat flow per unit area) where the bigger the number, the better the building insulation's effectiveness. R-value is the reciprocal of U-value. The R-value can be expressed in SI units, typically m^2K/W (or equivalently to $m^2°C/W$) or in the United States, R-values are given in units of $ft^2°F/Btu$. The conversion between SI and US units of R-value is 1 $h·ft^2°F/Btu$ = 0.176110 $K·m^2/W$, or 1 $K·m^2/W$ = 5.678263 $h·ft^2·°F/Btu$.
Low temperature:	Typically temperatures lower than -18^{o}C.
Medium temperature:	Typically temperatures higher than -5^{o}C.
PIR:	Polyiscyanurate (PIR), an insulating foam product, has a higher thermal rating than Expanded Polystyrene (EPS).
Remote RDC:	A refrigerated display cabinet with its refrigerating machinery sited remote from the cabinet structure.
Screw compressor:	A rotary screw compressor is a type of gas compressor which uses a rotary type positive displacement mechanism; either a single screw or two counter rotating Helical Screws.

Scroll compressor:	A Scroll compressor uses two interleaved scrolls to pump, compress, or pressurize fluids such as liquids and gases.
Secondary loop refrigeration system:	A system which is so designed with two basic loops of refrigerating fluid flow, the primary one may be a conventional direct expansion of a phase change refrigerant, cooling a liquid flow that is pumped to the secondary loop. The primary loop utilises considerably less refrigerant in the closed short circuit, generally restricted to the plant room location. The secondary loop may consist of a Heat Transfer fluid being circulated to all of the heat exchange sites.
Self-contained RDCs:	Refrigerated display cabinet with its refrigerating machinery contained integrally within the structure.
Semi-hermetic compressor:	A compressor which is connected to its driving motor within an accessible enclosure. The enclosure is hermetically sealed to retain the refrigerant and oil contents, along with the electrical stator windings of the motor.
Test packs:	ISO type M packages for temperature testing as detailed in AS1731-4.2003 Clause 5.2
Walk-in coolroom (WIC):	A walk-in coolroom is a structure formed by an Insulated enclosure of walls and ceiling, having a door through which personnel can pass through and close behind them. The floor space occupied by this structure, may or may not be insulated, depending on the operating temperature level.

Abbreviations

AUD	Australian dollar
BaU	Business as usual
BCA	Building Code of Australia
CO2-e	Carbon dioxide equivalent units
COP	coefficient of performance
CPRS	Carbon Pollution Reduction Scheme (Australia)
E3	Equipment Energy Efficiency Committee (Australia & New Zealand)
EC	European Commission
EPS	expanded polystyrene
GHG	greenhouse gas
GW	gigawatt (1 watt x 10^9)
GWh	gigawatt-hour (1 watt x 10^9)
HEPS	high efficiency performance standards
IEA	International Energy Agency
IEC	International Electrotechnical Commission
ISO	International Standards Organisation
kW	kilowatt (1 watt x 10^3)
kWh	kilowatt-hour
kWr	kilowatts of refrigeration
MCE	Ministerial Council on Energy
MEPS	minimum energy performance standards
Mt	megatonne (ie million tonnes)
NPV	net present value
NZD	New Zealand dollar
OBPR	Office of Best Practice Regulation (Australia)
PIR	polyiscyanurate insulation
RDC	refrigerated display cabinet
RSC	refrigerated service cabinet
RIS	regulatory Impact statement
t	tonnes
TEC/TDA	total energy consumption (kW/day)/Total Display Area (m^2)
TWh	terawatt-hours (1 watt-hour x 10^{12})
Wh	watt-hour
WIC	walk-in coolroom
VA	voluntary agreement

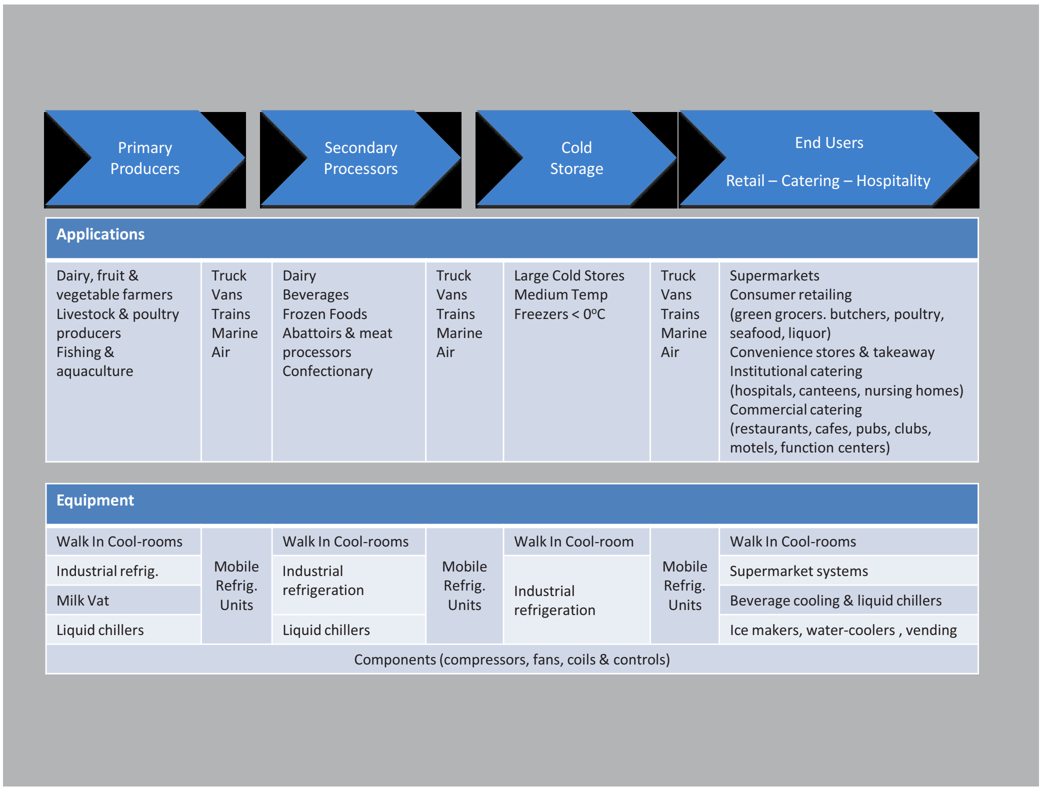
1 Introduction

The non-domestic refrigeration sector spans a wide range of technologies, and suppliers of products and services from small specialised operations to large companies that provide multiple products across Australia and New Zealand.

End-users are similarly diverse, including national supermarket and fast-food chains, large processors and distributors of foodstuff, fishing fleets, schools, cafes and restaurants.

All of these are participants in the cold food chain, sometimes called the commercial refrigeration sector, which is illustrated in Figure 1. However since this report also spans some industrial applications, the sector is referred to as 'non-domestic' in this document.

Figure 1: The cold food chain



Source: Expert Group, 2009

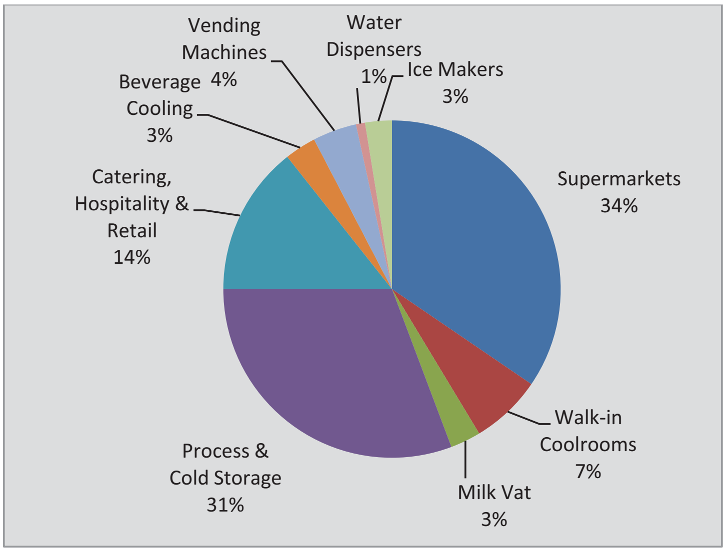
It is estimated that refrigeration in the non-domestic sector in Australia was responsible approximately 13,400 GWh of electricity in 2008. This does not include diesel used in providing mobile refrigeration. Greenhouse gas emissions for the complete sector in 2008 are estimated 13.7 Mt CO_2-e. A breakdown of electricity consumption and greenhouse gas emissions by major application sectors is shown in Table 1 and Figure 2.

Table 1: Estimated distribution of electricity consumption in non-domestic refrigeration, Australia, 2008

By Application Sectors	Equipment Types	Electicity Consumption (GWh p.a.)	Emissions (kt CO_2-e)
Supermarket Industry			
Central Plant	Rack System & RDC	3,926	3,953
Stand Alone Unitary Equip	Medium Cond Unit & Evap	508	512
Stand Alone Self Contained Equip	Self Contained Equip	185	186
Walk In Coolrooms	Small, Medium, Large	914	920
Chillers & Milk Vat			
Milk Vat: Liquid Chiller	Liquid Chillers	226	228
Milk Vat: Belt Drive	Belt Drive Units	164	165
Process and cold storage refrig.			
Industrial refrigeration	Industrial Refrigeration Equipment	630	634
Packaged liquid chillers	Liquid Chillers	2,855	2,875
Cold Storage & Distribution	Industrial refrigeration & large cond units	630	634
Catering, Hospitality & Retail			
Institutional & Commercial	Self Contained (integral or remote)	1,915	1,928
Beverage Cooling	Beer coolers: Refrigeration	108.5	109
	Beer coolers: Glycol pumps	115.3	116
	Post mix	179.6	181
Transport Refrigeration			
Truck Refrigeration	Truck Refrigeration Systems	-	127
Fishing Vessel Refrigeration	Fishing Vessel Refrigeration	-	98
Refrig. Beverage Vending Machines	Merchandising	563	567
Water Dispensing Equipment	Refrigeration Appliances	116	117
Ice Makers	Refrigeration Appliances	343	345
Totals		**13,377**	**13,695**

Source: MEA modelling estimates (see section 11 for further details)

Figure 2: Distribution of electricity consumption in non-domestic refrigeration, Australia, 2008



Source: MEA modelling estimates (see section 11 for further details)

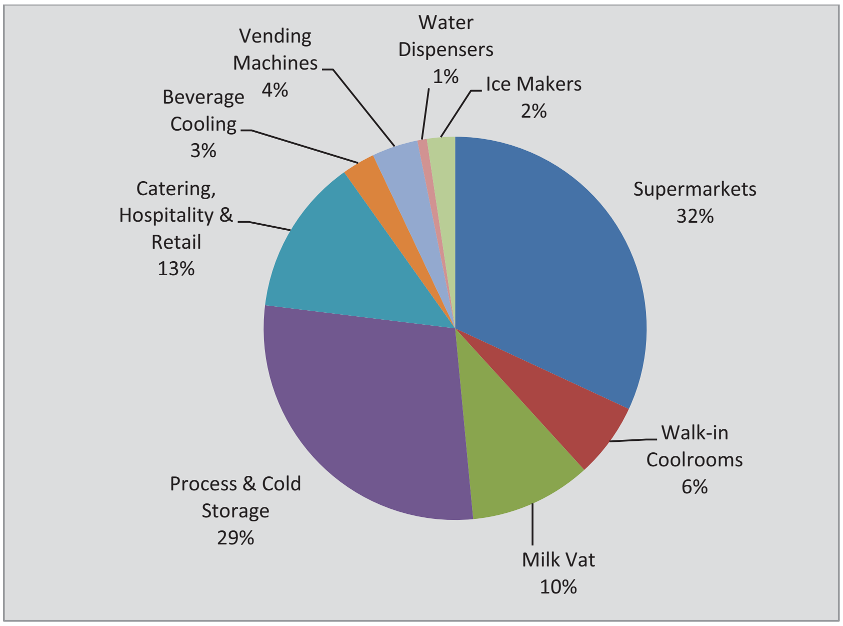
In New Zealand, electricity consumption in the non-domestic sector is estimated to be 2,850 GWh in 2008 (not including diesel for mobile refrigeration). Greenhouse gas emissions for the complete sector in 2008 are estimated 1.7 Mt CO_2-e. A breakdown of electricity consumption and greenhouse gas emissions by major application sectors is shown in Table 2 and Figure 3.

Table 2: Estimated distribution of electricity consumption in non-domestic refrigeration, New Zealand, 2008

By Application Sectors	Equipment Types	Electicity Consumption (GWh p.a.)	Emissions (kt CO_2-e)
Supermarket Industry			
Central Plant	Rack System & RDC	779	467
Stand Alone Unitary Equip	Medium Cond Unit & Evap	101	60
Stand Alone Self Contained Equip	Self Contained Equip	37	22
Walk In Coolrooms	Small, Medium, Large Cond Units	181	109
Milk Vat		295	177
Process and cold storage refrig.			
Industrial refrigeration	Industrial Refrigeration Equipment	125	75
Packaged liquid chillers	Liquid Chillers	567	340
Cold Storage & Distribution	Industrial refrigeration & large cond units	125	75
Catering, Hospitality & Retail			
Institutional & Commercial	Self Contained (integral or remote)	380	228
Beverage Cooling	Beer coolers: Refrigeration	22	
	Beer coolers: Glycol pumps	23	
	Post mix	36	21
Transport Refrigeration			
Truck Refrigeration	Truck Refrigeration Systems	-	25
Fishing Vessel Refrigeration	Fishing Vessel Refrigeration	-	19
Refrig. Beverage Vending Machines	Merchandising	112	67
Water Dispensing Equipment	Refrigeration Appliances	23	14
Ice Makers	Refrigeration Appliances	68	41
Totals		**2,873**	**1,741**

Source: MEA modelling estimates (see section 11 for further details)

Figure 3: Distribution of electricity consumption in non-domestic refrigeration, New Zealand, 2008



Source: MEA modelling estimates (see section 11 for further details)

This understanding of the sources of electricity consumption and greenhouse gas emissions indicates areas of priority for energy efficiency initiatives used as the basis for more detailed analysis in this report.

The following sections examine the key refrigeration technologies used for these applications and describe the market framework in these segments. In each, the opportunities for increased energy efficiency are identified, as well as the key barriers that currently prevent the uptake of energy efficient equipment and services to a level that is economically optimal. This information is used as the bases for making policy recommendations, summarized in the next section.

2 Summary of recommendations

The following section identifies the major recommendations for refrigeration technologies and market segments (other than refrigerated cabinets) as part of the 10 Year Strategic Plan for the non-domestic refrigeration sector being developed by the Equipment Energy Efficiency Committee. These recommendations are summarised in the Draft Strategic Plan '***In from the Cold***', to be finalised in the first half of 2010.

Following consultation with industry and other stakeholders, the measures adopted in the Strategic Plan will be implemented in stages over the next 10 years. The work plan for the first three years will be agreed as part of the Strategic Plan, with further three-yearly work plans developed over the course of the strategy. A review of the work plans will be conducted in the final year.

2.1 Compressors

- Minimum energy performance standards (MEPS) should be introduced for all compressors with a displacement between 1.4 to 836m^3/hr offered for sale in Australia and New Zealand at the earliest opportunity that allows for reasonable adjustment by suppliers and customers. It is considered likely that this might be towards the end of 2012;
- MEPS levels should be based on the calculated coefficient of performance (COP) based on input power and the refrigerating capacity of the compressor tested according to EN 21900 (2005) and EN 13771-1 (2003), at +5°C[1] (50°C[2]) for medium temperature applications, and at -25°C (55°C) for low temperature applications;
- All compressors offered for sale in Australia and New Zealand should be required to be registered in a similar manner to other products regulated for energy efficiency in these countries. It should be sufficient for the registration of technical performance to be made on the basis of a self-declaration based on in-house tests or on a rating undertaken by ASERCOM;
- In addition to the establishment of minimum energy performance levels, it is recommended that high efficiency performance standards (HEPS) COP levels should also be set to reflect the best performing products in the market. Further investigation by government and industry into the most effective means of assisting the promotion of these products is recommended.
- The following MEPS and HEPS levels are proposed for medium temperature applications (+5°C evaporator temperature):

  MEPS: Minimum COP = $1 + (1.85 * \Phi_0 / (\Phi_0 + 2600))$

  High Efficiency: Minimum COP = $1.4 + (1.60 * \Phi_0 / (\Phi_0 + 2100))$

  Where: Φ_0 = Cooling Capacity (Watts)

- The following MEPS and HEPS levels are proposed for low temperature applications (-25°C evaporator temperature):

  MEPS: Minimum COP = $0.7 + (1.10 * \Phi_0 / (\Phi_0 + 1300))$

  High Efficiency: Minimum COP = $1.1 + (0.79 * \Phi_0 / (\Phi_0 + 1800))$

  Where: Φ_0 = Cooling Capacity (Watts)

[1] Evaporating temperature (°C) at suction dew point.
[2] Condensing temperature (°C) at discharge dew point.

2.2 Fan Motors

- Minimum energy performance standards (MEPS) are introduced for fan motors used in non-domestic refrigeration applications, with an output power rating of between 5 Watts and 2,000 Watts;
- MEPS should apply to fan motors offered for sale in Australia and New Zealand at the earliest opportunity that allows for reasonable adjustment by suppliers and customers. It is considered likely that this might be towards the end of 2012.
- The following MEPS levels are recommended:
  - All single-phase fan motors used in non domestic refrigeration with an output power rating of between 5 Watts and 70 Watts offered for sale shall have an energy efficiency of 60% or greater;
  - All single-phase or three-phase fan motors used in non domestic refrigeration with an output power rating of between 71 Watts and 2,000 Watts offered for sale shall have an energy efficiency of 90% or greater. This requires further consideration in order to maintain consistency with other MEPS regulations;
- Further consideration should be given to the relationship with AS/NZS 1359, with the potential to incorporate these new requirements within future revisions of AS/NZS 1359;
- Further consideration should be given to the appropriate measurement method(s), including an comparative examination of IEC 60034-2-3 (draft) and the US test methods;
- Once the international energy efficiency standard for fan assemblies has been completed, ISO 12759, consideration should also be given to the extension of MEPS to these products.

2.3 Supermarket refrigeration

2.3.1 Store benchmarks

- The supermarket industry should be encouraged to adopt energy intensity benchmarks expressed in terms of total electricity consumption per store unit area per year (kWh/m^2 p.a.); where area is defined as trading floor or store area;
- Benchmarks should be designed to drive cost-effective investment in the supermarket industry over a sustained period of time. Therefore benchmarks should be set for intervals of not more than five years to 2020 or later;
- Given the concentration of ownership in the supermarket industry in Australia and New Zealand, it is feasible that that these benchmarks could be adopted as a voluntary agreement, with regular reporting arrangements to the E3 Committee;
- Should this prove difficult to negotiate or at the behest of the industry, these benchmarks should be adopted as regulations.
- Requirements for regular reporting and verification will need to be included in any agreement or regulation.
- Table 3 provides the proposed initial benchmarks to be met by 2013 for categories of large, medium and small sized stores;

Table 3: Proposed MEPS (kWh/m^2 p.a.) by store size

Category	Size of trading floor size (m^2)		MEPS Energy intensity (kWh/m^2 p.a.)
	Range	Average	
Large	≥ 2,750	3,800	820
Medium	≥1,500 and < 2,750	2,500	850
Small	< 1,500	650	980

- In order to determine future benchmarks, performance data provided by the major food retailers directly, or via the *National Greenhouse and Energy Reporting Act 2007* (NGERS), should be analysed. This may also lead to a further refinement of the benchmarks to take into account the different effects of full service supermarkets versus stores with less refrigeration (for example a measure of the proportion of chilled and frozen Stock Keeping Units versus other merchandise) and stores with different air conditioning arrangements such as stand-alone or supplied by a shopping centre.

2.3.2 Open display cabinets

- All new low temperature display cases to be horizontal 'coffin' style with sliding lids by 2012, rather than vertical 'up-right' freezers that spill cold air into supermarket aisles when doors are opened;
- Existing low temperature display cases to have doors retro-fitted by 2015 with solid doors on vertical 'up-rights' and sliding lids on 'coffin' style freezers;
- New medium temperature refrigerators to have doors (either solid or high performance glass doors or efficient air curtain arrangements to create zero air spillage) by 2015;
- Existing medium temperature refrigerators to have night blinds by 2015 or to be replaced;
- It recommended that these be adopted by the supermarket industry as a voluntary agreement.
- As with the benchmarking recommendation, provisions for monitoring and verification will need to be included within any voluntary agreement.

2.4 Walk-in coolrooms

a) The adoption of minimum energy performance standards on all structural aspects that affect the thermal performance of the WIC and major equipment, harmonised with the regulatory requirement for WICs in force in the United States. These include:

   - Insulation panels for walls, ceilings and doors to have an R-value of at least 4.5 m^{2}K/W (equates to 100mm PIR or 200mm EPS) on medium temperature WICs and 6.0 m^{2}K/W (thicker than 150mm PIR) on low temperature WICs;
   - Minimum thermal insulation ratings on floors of at least 4.9 m^{2}K/W for all WICs;
   - Transparent windows and doors to have double glazed on medium temperature WICs and triple glazed on freezers; all glass panes to have heat reflective treatment and gas fill;
   - Proper sealing of room, which prescribes the joins of insulation panels, types of doors and door gaskets;
   - Energy-efficient lighting with interior lights to use light sources with an efficacy of 40 lumens per watt or more, and lights in doors to have an efficiency equal to or better than LED lights;

- Anti-sweat heater controls that sense humidity and switch off when not required rather operating constantly; and
- Defrost controls to be 'demand' or 'adaptive' (sometimes referred to as 'smart' defrost) controls rather than using a simple timer to initiate defrosting.
- High-efficiency refrigeration compressors, as recommended in Section 3
- Evaporator and condenser fan motors meeting MEPS levels as recommended in Section 4.

2.5 Process and cold storage

- Government and industry organisations should combine to establish an online benchmarking facility to provide best practice information to the Cold Storage industry;
- Government and industry should set appropriate benchmark targets and key performance indicators by a date not later than 2011, based on the data on individual sites collected through this tool, and other sources;
- Governments should further investigate how such benchmarks and key performance indicators should be applied in order to be most effective, including through voluntary agreements with industry or regulation.

2.6 Milk vats

Contributing to energy savings of milk vats are the proposed measures for compressors and fan motors in this strategy; however it is still important to maintain a good level of activities promoting industry best practice. It is recommended that the following options are further investigated:

- Mechanisms to develop and distribute well targeted information, including industry best practice and benchmarks.
- Work with government and industry stakeholders to consider incentives for the adoption of best practice and investment in equipment that is focused on energy efficiency opportunities.

The New Zealand Government may consider this an area for special attention, given that milk vats account for 22% of NZ non-domestic refrigeration electricity consumption.

2.7 Beverage cooling

Since most of the potential savings will be achieved through horizontal measures for compressors and fan motors in this strategy, and consideration of measures for pumps are likely to be included in the Industrial Equipment Strategy, no additional measures are proposed.

2.8 Mobile Refrigeration

The key measures proposed for the mobile refrigeration sector are to further investigate with relevant government agencies and the industry the following:

- The design and use of materials to increase insulation capacity of refrigerated rolling stock to enhance benefits such as reduced fuel use, greater quality control of products and reduce risk of product spoilage.

- The feasibility of increasing the maximum permitted width of trucks to 2.6m to allow space for adequate insulation materials when standard pallets are used.
- Ensuring that new refrigerated transport products are insulated to a minimum of R3.9 m^2K/W. Investigate mechanisms such as regulation to achieve this.
- Specific incentives to encourage the uptake of practices that increase the energy efficiency of rolling stock and develop and promote targeted information on 'best practice' for this sector.
- The feasibility of putting in place emission standards for refrigeration transport systems similar to the US EPA Tier 4 non-road engine standards and the CARB in-use program.

3 Compressors

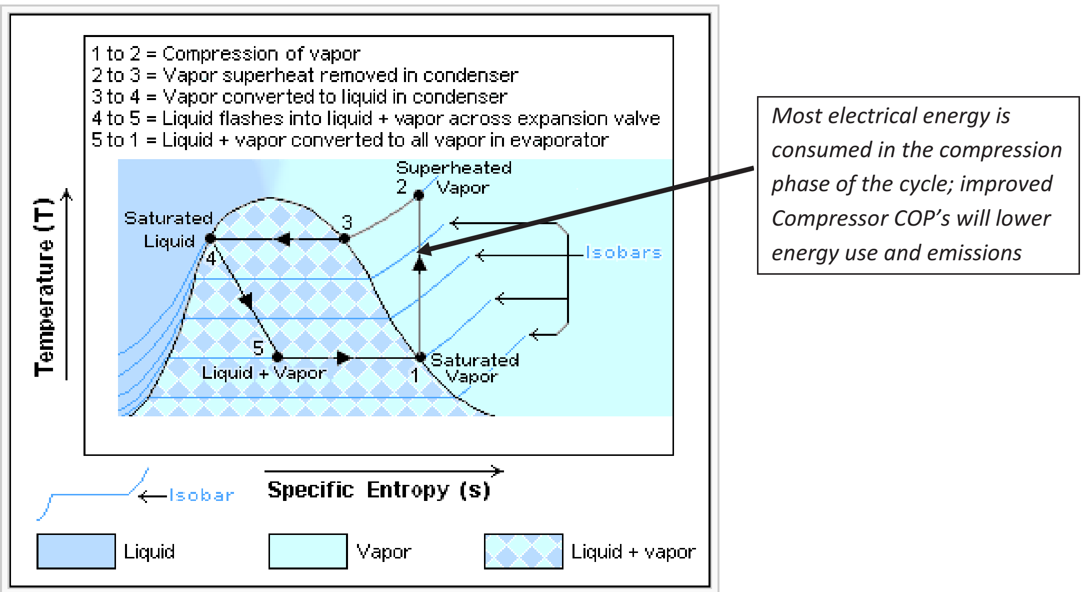
3.1 Description of technology

The compressor is often referred to as the heart of the refrigeration system as it is the most critical component in the vapour compression cycle. Its main function is to compress the circulating refrigerant in the form saturated vapour turning it into a hot, superheated vapour. This is then condensed using either air or water. All refrigeration compressors considered in this report are driven by an electric motor which may be either single or three-phase.

The compressor function is best described by the thermodynamics of the cycle and is analysed in Figure 4 below. In this cycle the circulating refrigerant enters the compressor as a vapour.

From point 1 to point 2, the vapour is compressed at constant entropy and exits the compressor superheated. From point 2 to point 3 and on to point 4, the superheated vapour travels through the condenser which first cools and removes the superheat and then condenses the vapour into a liquid by removing additional heat at constant pressure and temperature. Between points 4 and 5, the liquid refrigerant goes through the expansion valve where its pressure abruptly decreases, causing flash evaporation and auto-refrigeration of, typically, less than half of the liquid.

Figure 4: Pressure entropy diagram



3.1.1 Types of compressors and their configurations

There are three main types of compressor technology, as follows:

- Hermetic – the compressor and electric drive motor are totally sealed in an outer shell;
- Semi-Hermetic (or accessible hermetic) – the compressor and electric motor are in a single shell but can be disassembled;

- Open Drive – the electric motor drives the compressor externally by a direct drive coupling or belts drive by pulleys on the motor and compressor.

Refrigeration compressors are sized according to the volume displaced by the compressor per unit of time and is usually expressed in cubic meters per hours.

Within the three major compressor categories, there are several subcategories and these are discussed in more detail in the following section.

3.1.1.1 Hermetic reciprocating compressors- displacement[3] 1.4 to 9.2m^3/hr

Typically with single-phase motors for smaller displacement and three-phase motors in larger displacement, this type of hermetic compressor has pistons/rods that are driven directly by an internal electric motor. These sizes of compressors have 1 or 2 pistons usually.

Figure 5: Hermetic reciprocating compressor-small

3.1.1.2 Hermetic reciprocating compressors –displacement 6 to 88m^3/hr

These larger hermetic compressors have 2 to 4 pistons and, because of the start-up power required, are commonly are driven directly by three-phase electric motors.

Figure 6: Hermetic reciprocating compressor-medium

[3] Compressor displacement often expressed in cc/rev, these have been converted using a conversion factor of 0.171 or 1cc per rev = 0.171.

3.1.1.3 Hermetic scroll compressors –displacement 6 to 88m^3/hr

This design has two interleaved Archimedean spirals of the same size, one of which remains stationary while the other rotates and compresses the gas between the two scrolls, (See Figure 7 and Figure 8).

The fixed scroll and internal electric motor are attached to the same drive shaft. This type of compressor was introduced to achieve higher efficiency levels for refrigeration compressors since scroll-type compressors use less power to rotate than pistons and cranks. Larger displacement compressors have more spirals and tend to be three-phase motors.

Figure 7: Scroll compression function

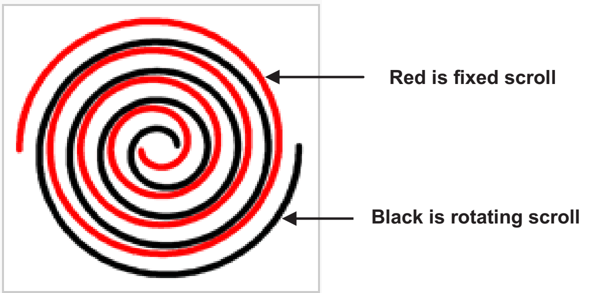
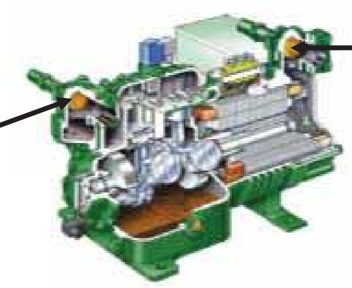


Figure 8: Hermetic scroll compressor

3.1.1.4 Semi-hermetic reciprocating compressors-reed valve- displacement 4 to 185m^3/hr

This design has 2 to 8 pistons to achieve the required displacement, driven directly by an internal electric motor. The electric motors to drive this displacement range are mostly three-phase due to the amount of power needed to start them. The suction gas enters the compressor over the electric motor to cool the motor and readies the vapour further for compression.

Figure 9: Semi-hermetic 4 cylinders, reed valve compressor



3.1.1.6 Semi-hermetic reciprocating compressors-discus valve4 to 185m^3/hr

Similar to the Reed Valve compressor, this design has a Delta Reed valve plate design that reduces refrigerant re-expansion volume (See Figure 10) to a minimum, improving the energy efficiency compared to the standard reed valve plate design technology. The suction gas enters the compressor over the motor and readies further the vapour for compression.

Figure 10: Discus valves vs. Reed valves

3.1.1.7 Semi-hermetic screw compressors- displacement 84 to 8,140m^3/hr

Helical screws mesh and rotate to create a positive-displacement compression of the refrigerant. There are two screws with a matting profile: a female having concave inlets and male with convex helical inlets. The screws rotate in the opposite direction with the female screw receiving the driving power and transmitting this power to the male screw through a set of synchronization gears that are driven by the internal electric motor (see Figure 11). The suction gas enters the compressor over the motor and readies the vapour for compression. Since the helical screws require less power to drive than reciprocating type compressors, they are generally more energy efficient These compressors are usually three-phase only.

Figure 11: Semi-hermetic screw compressor

3.1.1.8 Open drive screw compressors- displacement 84 to 8,140m^3/hr

This type of compressor is similar to the semi-hermetic screw compressor except that the screws are driven by an external electric motor that is generally configured with direct drive coupling to a three-phase totally enclosed fan-cooled (TEFC) motor. This compressor is generally used in medium and higher temperature applications and is more energy efficient than reciprocating type compressors.

Figure 12: Small displacement open-drive screw compressor

3.1.1.9 Open drive reciprocating compressors–displacement 20 to 836m^3/hr

This type has pistons/rods driven by a crankshaft that is driven by an external electric motor. The external electric motor on the smaller sizes are often driven by belts and pulley attached to TEFC three-phase motors and the compressor. Some dairy farms use single phase motors because three phase power is not available. The majority of the larger sizes are generally configured with direct drive coupling to a three-phase TEFC motor.

Figure 13: Large open drive reciprocating compressor- typically used in industrial refrigeration

3.1.2 Compressors definitions summary

Throughout this document references are made to common compressor measures:

- Nominal kW capacity;
- Displacement in cubic metres / hour (m^3/hr).

Table 4 below summarises these references by the various compressor types:

Table 4: Typical nominal capacities and displacements for types of compressors

Compressor Type	Capacity Range Nom. Rating R404A @ -5 SST/40°C Cond.	Displacement (m³/hr)
Hermetic Reciprocating – Small	0.19 to 1.34kW	1.4 to 9.2 m³/hr
	(1/4 to 1.8HP)	
Hermetic Reciprocating – Large	1.35 to 27.5kW	6 to 46 m³/hr
	(1.81 to 13.00HP)	
Hermetic Scroll – Large	3.5 to 53kW	6 to 88 m³/hr
	(2 to 30HP)	
Semi - Hermetic - Reed Valve	1.8 to 90kW	4.0 to 185.0 m³/hr
	(0.8 to 70HP)	
Semi - Hermetic - Discus Valve	1.8 to 90kW	4.0 to 185.0 m³/hr
	(0.8 to 70HP)	
Semi- Hermetic & Open Drive	84 to 1905kW	84.0 to 8140 m³/hr
Screw type	(13 to 1420HP)	
Open Reciprocating	8kW to 223kW	19.68 to 836m³hr
Belt or Direct Drive	(5 to 166HP)	(Ave RPM 1450)

3.1.3 Compressor energy efficiency

Compressor energy efficiency is measured by the coefficient of performance (COP)[4], where the COP is calculated as follows:

$$\textbf{COP} = \frac{\textit{refrigerating capacity of compressor (Watts)}}{\textit{energy consumed to drive the compressor (Watts)}}$$

A chart exhibiting relative COPs for different technologies, is shown later in this document.

Compressor manufacturers are acutely aware of the need to produce products that consume less energy and have improved COP[5] ratings. The majority of compressor manufacturers have active research and product development programs to achieve these ends. Many of these manufacturers have also been working on their compressor products to operate with natural refrigerants (CO_2 and NH_3); and although trials to date have not produced energy savings using these refrigerants, there will impacts in terms of reduced greenhouse gas emissions from refrigerant leaks.

Major compressor technology developments generally evolve out of economies of scale from air conditioning compressors. For example, the scroll compressor was initially developed for HVAC applications, demonstrating up to 30% improvement compared to previous technology.

Improved gas management though the compressor; optimised motor matching to the specific compressor displacement and application duty are likely to bring COP improvements with existing technology (see section 3.5).

[4] Defined in EN12900 European Standard on calculating COP's.

[5] UK Government set voluntary COP targets for Semi-Hermetic Compressors with financial incentives to end users, mostly Supermarkets. Medium temperature application targets over 10 years in moving from a COP of 3.36 to 3.65.

3.2 Energy efficiency of major compressor types

The average COP of the seven major compressor categories currently being offered in the market are shown in Table 5.

Table 5: Average COP of the seven major compressor categories currently being offered in the market

Compressor Type	Capacity Range Nom. Rating R404A @ -5 SST/40°C Cond.	Displacement m^3/hr	COP Av. Rating
Hermetic Reciprocating – Small	0.19 to 1.34kW (1/4 to 1.8HP)	1.4 to 9.2 m^3/hr	1.83
Hermetic Reciprocating – Large	1.35 to 53.0kW (1.81 to 30.00HP)	5.9 to 87.5 m^3/hr	2.00
Hermetic Scroll – Large	3.5 to 53kW (2 to 30HP)	5.9 to 87.5 m^3/hr	2.95
Semi - Hermetic - Reed Valve	1.8 to 90kW (0.8 to 70HP)	4.0 to 185.0 m^3/hr	2.70
Semi - Hermetic - Discus Valve	1.8 to 90kW (0.8 to 70HP)	4.0 to 185.0 m^3/hr	3.00
Semi- Hermetic & Open Drive Screw type	84 to 1905kW (13 to 1420HP)	84.0 to 8140 m^3/hr	3.20
Open Reciprocating Belt or Direct Drive	8kW to 223kW (5 to 166HP)	19.68 to 836m^3hr (Ave speed 1450rpm)	2.80

Not all of these major types of compressors compete for the same markets, as illustrated by the displacement range of each shown in Figure 14.

Figure 14: Displacement range of major types of compressors

Compressor Type	Displacement Range m^3/hr of Various Compressor Types												
	1	5	10	20	40	60	80	100	150	200	500	1000	10000
Hermetic Reciprocating - Small	1.4 to 9.2 m^3/hr												
Hermetic Reciprocating - Large		5.9 to 87.5 m^3/hr											
Hermetic Scroll - Large		5.9 to 87.5 m^3/hr											
Semi - Hermetic - Reed Valve		4.0 to 185.0 m^3/hr											
Semi - Hermetic - Discus Valve		4.0 to 185.0 m^3/hr											
Semi- Hermetic & Open Drive Screw type							84.0 to 8140 m^3/hr						
Open Reciprocating Belt or Direct Drive				19.68 to 836 m^3/hr									

3.3 Uses in commercial refrigeration

A wide variety of compressors are needed to service Australia's needs for commercial refrigeration. The following Table 6 outlines the end-use applications by compressor type and size.

Table 6: Compressor types and sizes by application

	Hermetic			Semi-Hermetic		Open Drive		Semi-Hermetic
	Reciprocating		Scroll	Recip': Reed	Recip': Discus	Recip'	Screw	Screw
Application	0.19 to 1.34kW	1.35 to 22.5kW	3.5 to 53kW	1.8 to 90kW	1.8 to 90kW	8 to 223kW	84 to 1905kW	84 to 1905kW
Beverage Cooling-Beer		✓	✓	✓	✓			
Beverage Cooling-Post Mix	✓	✓	✓					
Cold Storage-Warehousing						✓	✓	✓
Condensing Units	✓	✓	✓	✓	✓	✓		
Display Cabinets-Supermarket				✓	✓			
Food Processing-Large						✓	✓	✓
Food Preparation-Hospitality		✓	✓	✓	✓			
Ice Making Machines	✓	✓						
Milk Vats-Dairy		✓	✓	✓	✓	✓		
Self Contained Display Cabinets	✓							
Transport Refrigeration						✓		
Vending Machines	✓	✓						
Walk-In Coolrooms	✓	✓	✓	✓	✓			

3.4 Market profile

3.4.1 Sales & stock

Compressors sold in Australia are either imported already fitted in self contained equipment (such self-contained display cabinets, ice makers, refrigerated beverage vending machines) or sold as individual items in Australia. The latter are imported by either the local office of the overseas manufacturer or agents, who are typically industry wholesalers.

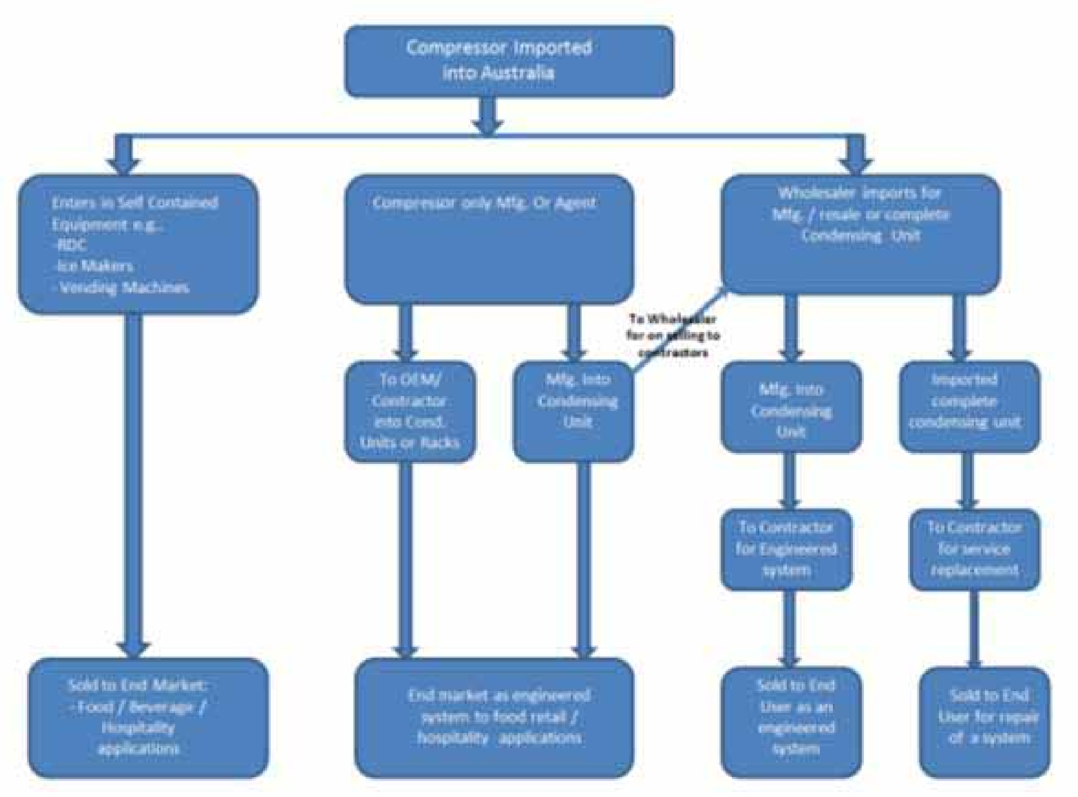
These importers often sell their products to local OEM's for applications like:

- Refrigerated Display cases;

- Condensing Units;
- Wholesalers, where the importer is the agent they sell them as locally made condensing units or as replacement compressor replacements.

All end sales are to refrigeration contractors who sell them to end users as an engineered refrigeration system or replacement components as shown in Figure 15.

Figure 15: Flow chart of imported compressors through channels to end markets



Industry sources[6] estimate the installed base of the main types of compressors are as shown in Table 7.

Table 7: Outlines compressor type, quantity and percentage of installed base

Compressor Type	Installed Base	% of Installed Base
Hermetic Small - 0.19 to 1.34kW	751,600	50.0%
Hermetic Large - 1.35 to 53.0kW	628,920	41.8%
Semi Hermetic Recip. -1.8 to 90kW	109,900	7.3%
Open Drive Recip. - 8 to 223kW	5,100	0.3%
Screw Semi-Herm & Open - 84 to 1905kW	8,280	0.6%
Totals	**1,503,800**	**100%**

[6] Cold Hard Facts

From the same survey material the overall industry average life-time of compressors is estimated to nearly 12 years, giving an annual sales volume of approximately 132,000 units per annum.

3.4.2 Suppliers

Table 8 shows the major suppliers for each of the compressor types.

Table 8: Major compressor brands and importers by type and size

Brand - Importer	Hermetic			Semi-Hermetic		Open Drive		Semi-Hermetic
	Reciprocating		Scroll	Recip': Reed	Recip': Discus	Recip'	Screw	Screw
	0.19 to 1.34kW	1.35 to 22.5kW	3.5 to 53kW	1.8 to 90kW	1.8 to 90kW	8 to 223kW	8 to 1,905kW	8 to 1,905kW
Bitzer				✓		✓	✓	✓
Copeland		✓	✓	✓	✓			
Cubigel-Airefrig	✓	✓						
Danfoss	✓	✓	✓					
Dorin - Heatcraft				✓				
Embraco-Aspera	✓	✓		-				
Frascold-Luve Pacific				✓				
Frick-Sabroe-Johnson Controls						✓	✓	✓
GEA-Grasso						✓	✓	✓
Hanbell-Heatcraft							✓	✓
Kulthorn Kirby-Heatcraft	✓	✓						
Mycom-Mayekawa						✓	✓	✓
Tecumseh-Actrol	✓	✓						

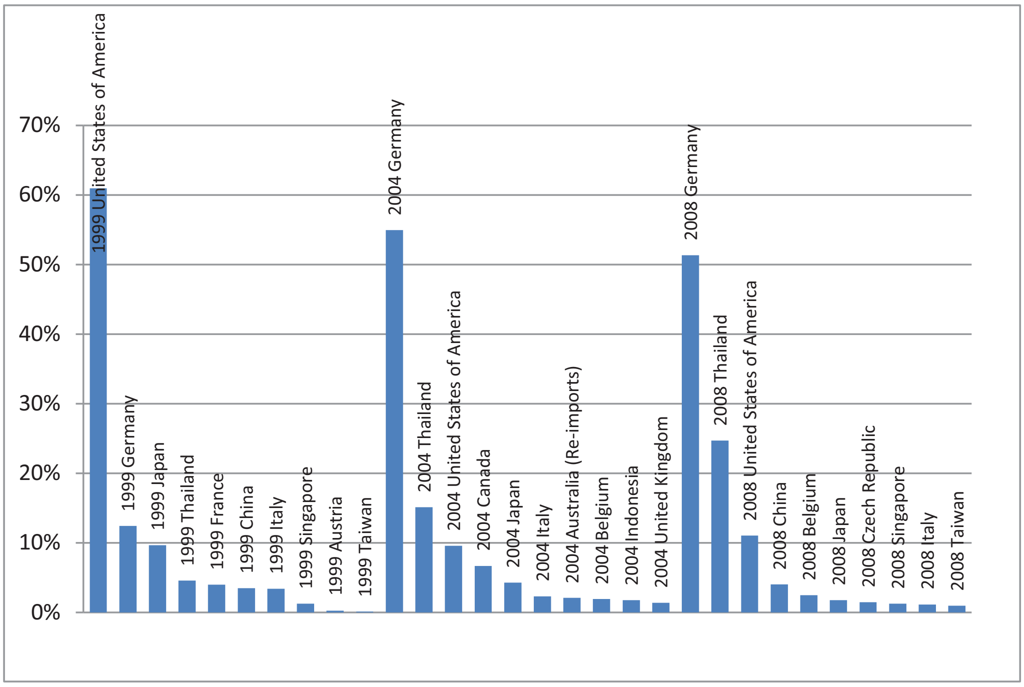
3.4.3 Countries of origin

Compressors are imported from a large number of countries; however the majority is sourced from Germany, Thailand and the United States. As shown in Figure 16, Figure 17 and Figure 18 and based on data provided by the Australia Bureau of Statistics[7] (ABS 2009) the share of imports from most major

[7] This data needs to be treated with some caution since some major importers of Compressors have either had the country of origin, the import value or quantity or all of those references suppressed for reasons of confidentiality. For example it is known that data from Airefrig, Actrol and Heatcraft (for Hermetic Condensing Units) and from Bitzer, Actrol, Heatcraft, and Emerson (for Hermetic and Semi-Hermetic compressors) has been withheld. However, in most cases, the data has consistently withheld for all the 10 year study period; therefore trends emerging can be meaningful.

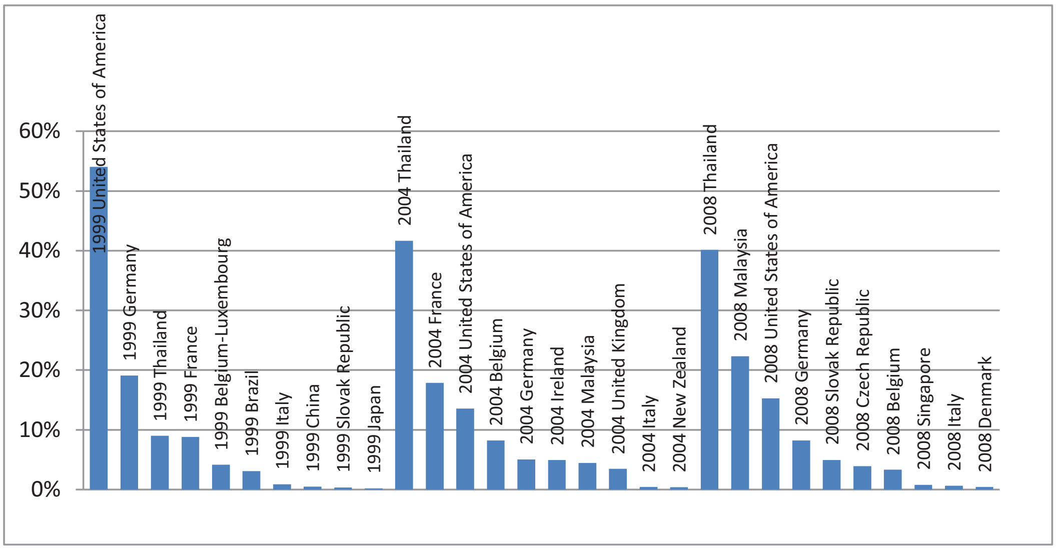
countries of origin has changed since 1999 within each compressor category; however these three countries have remained the most important suppliers.

Figure 16: Proportion of imports of sealed motor type compressors of a kind used in refrigerating equipment (excl. for automotive air conditioners) excl. 3.75 kW (ref: 8414300028) by value & by country of origin



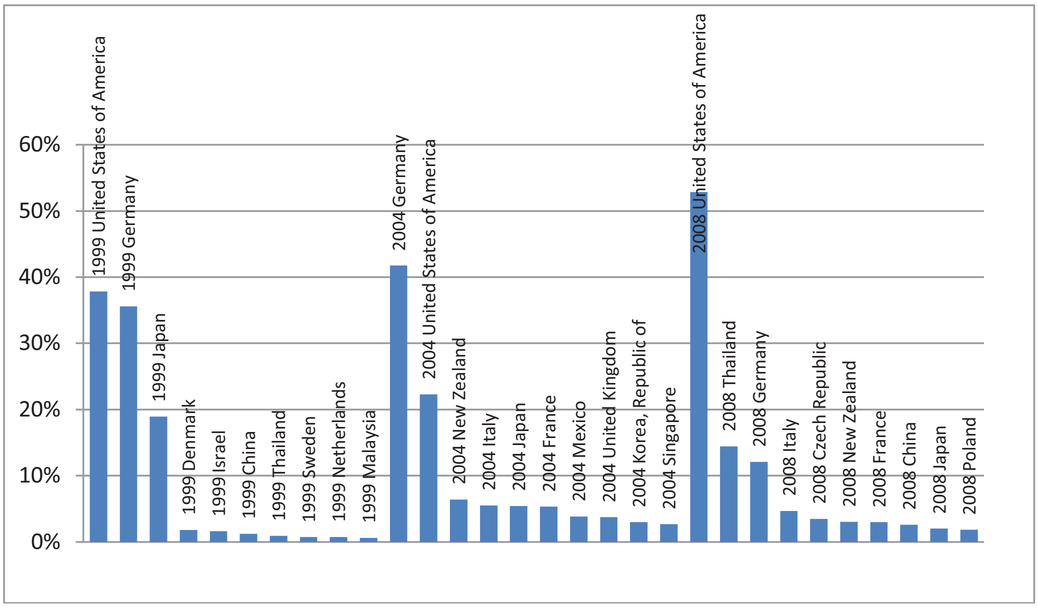
Source: ABS 2009

Figure 17: Proportion of imports of accessible hermetic type compressors of a kind used in refrigerating equipment (excl. for automotive air conditioners) excl. 3.75 kW (re: 8414300030) by value & by country of origin



Source: ABS 2009

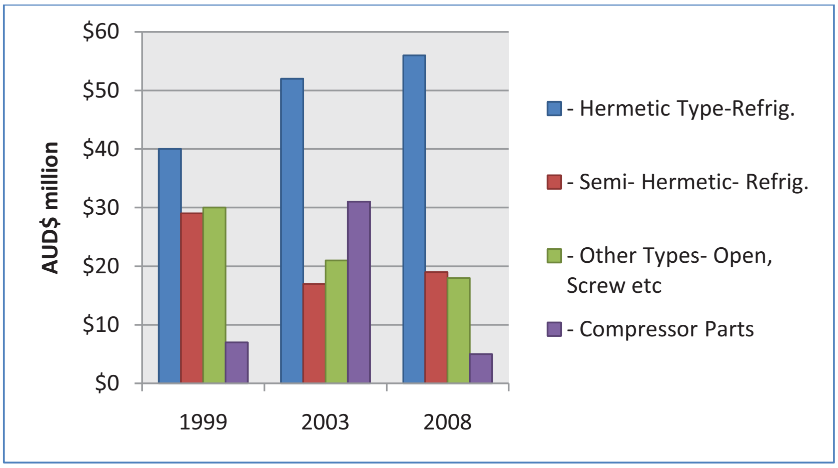
Figure 18: Proportion, imports of compressors of a kind used in refrigerating equipment (excl. for automotive air conditioners, sealed motor type, accessible hermetic type) excl. 3.75 kW (ref: 8414300032) by value & by country of origin



Source: ABS 2009

3.5 Market trends

Figure 19: Compressor imports to Australia by major type, 1990-2008



There are some encouraging signs of movement towards more energy efficient refrigeration compressors in Australia, driven by rising power costs. This is particularly noticeable in the above chart (Figure 19) where Hermetic Compressors over 3.75kW with higher COP's than Semi-Hermetic have increased by 50% between 2003 and 2008 where Semi-Hermetic types have not grown.

The market current trends include:

- An increased use of screw compressors replacing less energy efficient reciprocating type products with likely savings in the 5-10% range;
- Increased use of scroll Compressors and decline in reciprocating type, 30-35% energy savings possible;
- Use of R134a rather than R404A in screw compressors for medium to high temperature refrigeration, due to better refrigerant thermodynamic performance;
- The requirement for lower compressor sound level output needs in urban areas has resulted in an increased market for hermetic type compressors with design changes and sound attenuation materials;
- Compressor manufacturers are increasingly offering some popular reciprocating models with motors suitable for use with Variable Speed Drives (VSD's)[8];
- Test installations are underway with modified compressors (motors suitable for VSD and modified lubrication systems) having VSD' applied to them offering energy saving outcomes of 30-50% pa;
- One manufacturer, Copeland, now offers a version of the scroll compressor called ''digital scroll'', that provides modulation from 10% to 100% of nominal refrigeration capacity. It is claimed that this is less costly than VSD and saves 30% of the energy used by a conventional hermetic scroll compressor.

3.6 Energy consumption and greenhouse gas emissions

Compressors are used throughout the commercial refrigeration industry and account for between 40% and 50%[9] of all electrically powered components within the commercial refrigeration sector.

It is estimated that the energy consumption by compressors in non-domestic refrigerators in Australia totals between 4,800 and 6,000 GWh per annum, and is responsible for emissions between 4.8 and 6.0 Mt CO_2-e in Australia.

The following compressors are the largest users of electricity[10]:

- Semi Hermetic (reciprocating reed compressors, 1.8 to 90kW), consume 36% of compressor energy;
- Large Hermetic (scroll and reciprocating compressors, 1.35to 53kW), consume 33% of all compressor energy;
- Small Hermetic (reciprocating compressors, 0.19 to 1.34kW), consume 16% of all compressor energy.

Table 9 details all compressor types, their energy usage and emissions profiles.

[8] Note that it is also necessary to modify the lubrication system for low speed operation.
[9] Emerson Climate Systems.
[10] Cold Hard Facts.

Table 9: Total energy consumption by compressor type, Australia 2009

Compressor Type	Energy Consumed GWh per annum (50% use assumed)	Energy used % by Comp. Type	Emissions Mt CO_2-e
Semi Hermetic Recip. -1.8 to 90kW	2,160	36%	2.1
Hermetic Large Recip.& Scroll - 1.35 to 53.0kW	1,980	33%	2.0
Hermetic Small Recip. - 0.19 to 1.34kW	960	16%	1.0
Screw Semi-Herm. & Open- 84 to 1,905kW	660	11%	0.7
Open Drive Recip. - 8 to 223kW	240	4%	0.2
Totals	**6,000**	**100%**	**6.0**

3.7 Opportunities for improving energy consumption

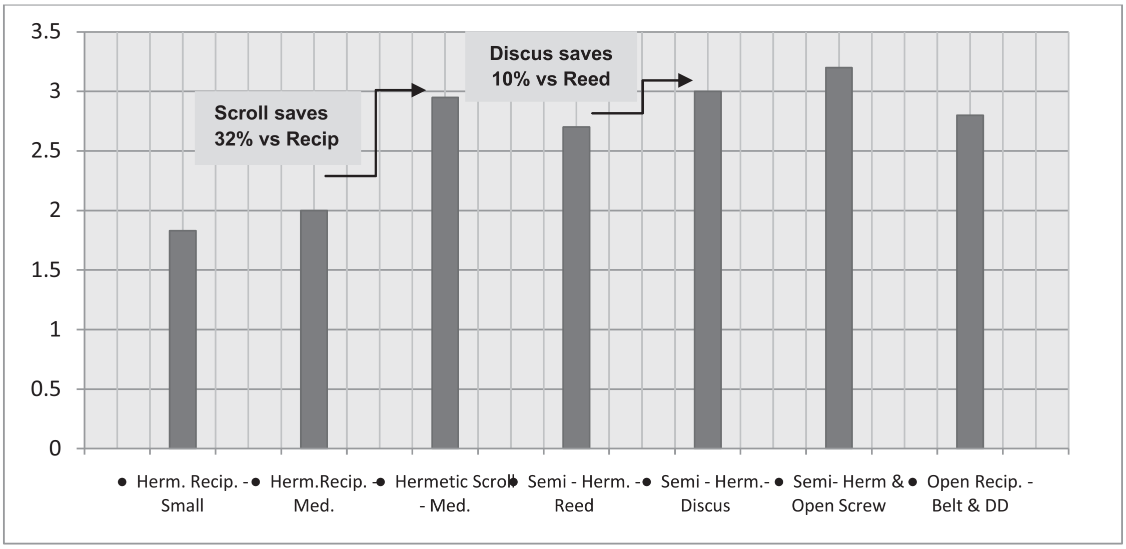
The current average COP of the installed base is approximately 2.0, while the COP of current sales is 2.2. Although this indicates an improvement, there are considerable opportunities to save energy through increasing the COP of products entering the market, both as new individual units and as replacement components within existing systems.

Table 10: Compressor types by installed base volume and average COP's

Compressor Type	Installed Base	COP Average
Hermetic Small Recip.- 0.19 to 1.34kW	751,600	1.8
Hermetic Large Recip & Scroll - 1.35 to 53.0kW	628,915	2.0
Semi Hermetic Recip. -1.8 to 90kW	109,900	2.7
Open Drive Recip - 8 to 223kW	5,100	2.8
Semi-Herm & Open Screw - 84 to 1,905kW	8,280	3.2
Totals	**1,503,795**	**1.98**

The impact of shifting the market towards more efficient compressor technologies is illustrated in Figure 20, and two particular examples discussed in the following paragraphs.

Figure 20: COP Ratings from public ratings of popular brands/ types used in Australia



3.7.1 Semi-hermetic reciprocating – change to discus or equivalent COP

There are two types of semi-hermetic reciprocating compressors offered on the Australian market; those with standard reed valves and another with discus valves. The latter provides energy savings of approximately 10 %. The largest market use for these types of these compressors is in supermarket segment.

Moving the market to discus type compressors is estimated to save 122 GWh p.a. by the end of a 10 year period, and reduce greenhouse gas emissions by 123 kt CO_2-e p.a.

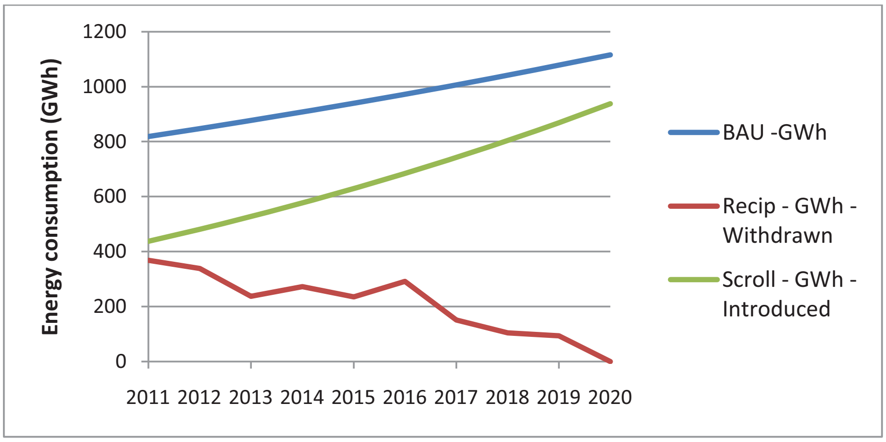
3.7.2 Scroll and reciprocating hermetic compressors – change 100% to scroll

Large sized (1.35 to 53kW) reciprocating and scroll hermetic compressors each have approximately 50% of the current market. The reciprocating type has an average COP of 2.0 and the Scroll type has an average COP of 2.95. These compressors are sold to contractors, fitted to air-cooled condensing units, and sold to OEMs for installation into engineered systems.

The market prices are similar for equivalent sizes for scroll type versus the reciprocating type. An energy saving of 32% can be achieved by using Scroll instead of using the reciprocating type.

Figure 21 shows the outcome of the market making this change over a 10 year period, offering saving of 178 GWh p.a., in addition an greenhouse gas emission reduction of 180 kt CO_2-e p.a.

Figure 21: BaU energy consumption and greenhouse gas emissions savings – switching from reciprocating hermetic compressors to scroll compressors



As noted above, the life of compressors are typically shorter than that of associated equipment and therefore the market for compressors includes the replacement of retired compressors within existing equipment. This needs to be considered in case there are physical or other limitations which may impede the switch to different, more efficient, compressor technology.

Generally, the more efficient compressors are not more bulky than products which they may replace, making it feasible to retrofit them into existing equipment. In some cases, new mounting holes will be required at the time of installation, or brackets to fix to existing mounts; however this is not considered a significant barrier or additional cost.

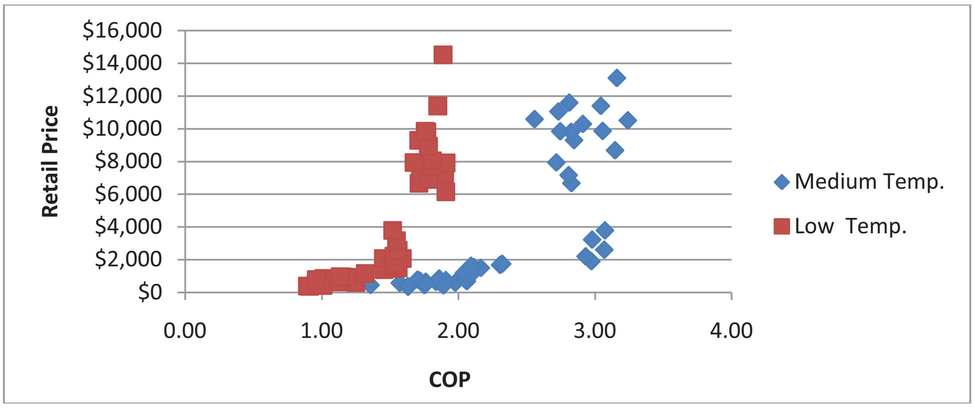
3.8 Barriers to energy efficiency

Discussions with various sectors of the industry have suggested that a major reason why more efficient compressors do not have a larger presence in the market is due to their higher capital cost and a reluctance of purchasers to consider the life-time savings available. The following section therefore examines the relationship between cost and efficiency for a range of products in the Australian market, and the analyses the life-cycle cost implications.

3.8.1 The capital cost and efficiency of compressors

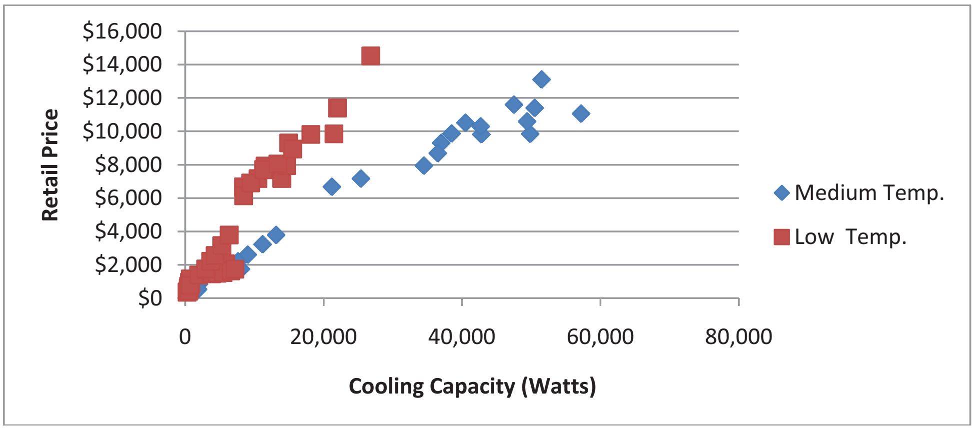
An examination of the Australian compressor market indicates that the capital cost of a compressor is not directly related to its energy performance. As shown in Figure 22, low cost products tend to have a low efficiency, but amongst mid-to-high value compressors the efficiency is variable and not strongly related to capital cost.

Figure 22: The relationship of efficiency and capital cost for medium and low temperature compressors in Australia



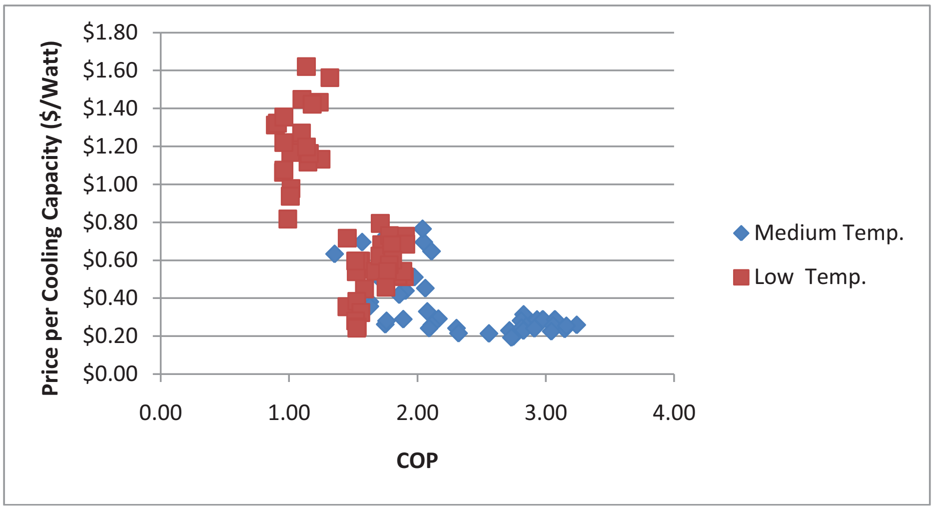
However, there is a far more direct relationship between capital cost and cooling capacity, probably because the cost of materials is a significant component of the final price of a compressor (see Figure 23).

Figure 23: The relationship of cooling capacity and capital cost for medium and low temperature compressors in Australia



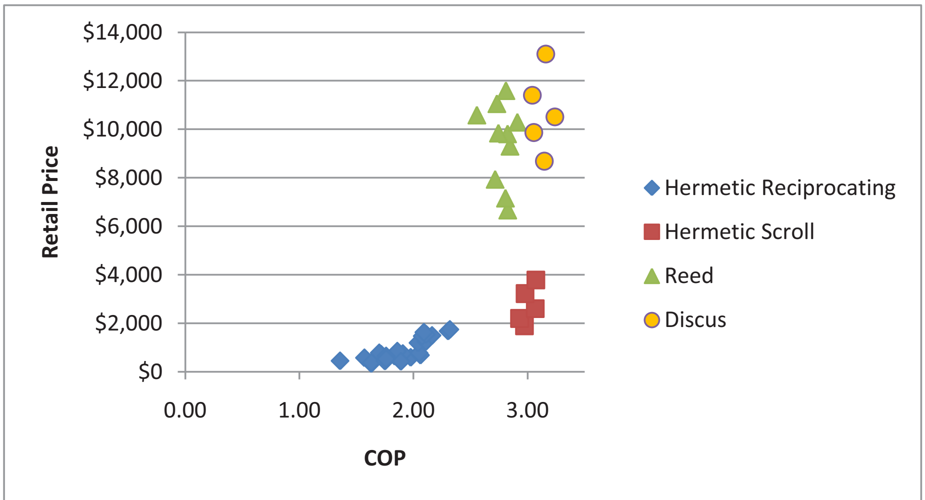
This situation means that, in general, more efficient compressors are cheaper than less efficient models per unit of cooling capacity. This appears to be the case for both medium and low temperature compressors, as shown in Figure 24.

Figure 24: The relationship of efficiency and capital cost per unit of cooling capacity for medium and low temperature compressors in Australia



Further analysis of data in Figure 25 for medium temperature compressors by major technology type shows how the market appears to be divided into three price segments (relating to rated size) and that there is little cross-over of technologies between these segments.

Figure 25: The relationship of efficiency and capital cost for medium temperature compressors in Australia by major technology type



3.8.2 Life-cycle cost analysis

The financial implications of moving to more efficient compressors are typically examined using life-cycle analysis comparing the total of capital and running costs for products which provide an equivalent level of service, while using differing levels of energy.

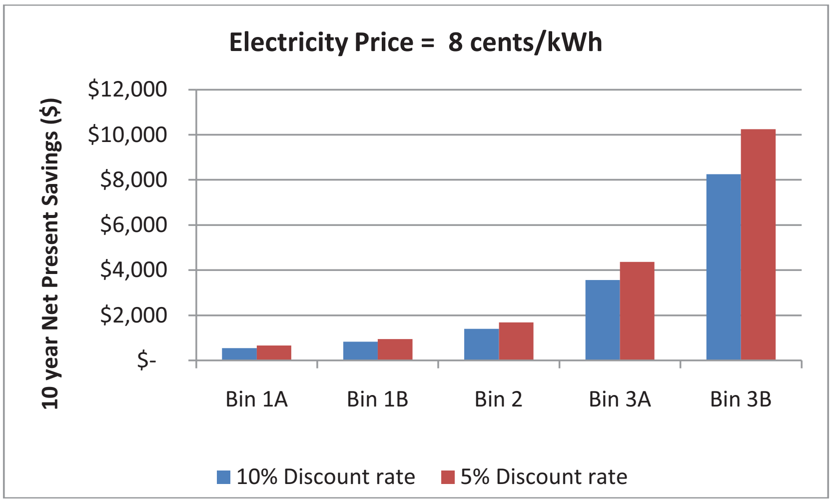
In this analysis, ten compressors comprising five sets of equivalent cooling capacity were selected as shown in Table 11. Using an industry average run-time of 16 hours/day, and a discounted retail price to reflect prices paid in the marketplace[11], the net benefit over ten years of purchasing the more energy efficient compressors are shown in Figure 26 and Figure 27. In both cases, annual discount rates of 10% and 5% are shown. Figure 26 illustrates the results for an electricity cost of 8 cents/kWh, while a price of 12 cents/kWh has been used in Figure 27.

These results show that the financial benefits of switching to more efficient compressors outweigh the costs in every example, and these benefits are significant for the larger compressors.

Table 11: Modelling parameters for life-cycle cost analysis

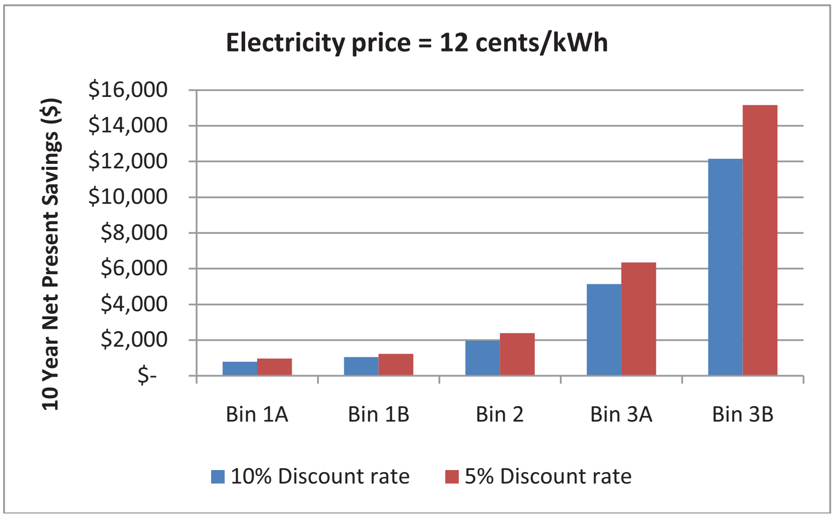
Cooling Capacity (Watts)	Model	Cooling Capacity (W)	COP	Energy reduction (%)
0 to <3,000	Bin 1A			
	Model 1	1,505	2.06	*19%*
	Model 2	1,530	1.70	
	Bin 1B			
	Model 3	1,924	2.11	*15%*
	Model 4	1,880	1.76	
3,000 to <30,000	Bin 2			
	Model 5	7,650	2.93	*13%*
	Model 6	6,913	2.30	
30,000 to <75,000	Bin 3A			
	Model 7	36,500	3.15	*9%*
	Model 8	34,500	2.72	
	Bin 3B			
	Model 9	50,500	3.04	*14%*
	Model 10	49,400	2.56	

Figure 26: 10 year net benefit for ten compressors, Australia 2009 (18hrs/day, 8 cents per kWh)



[11] Based on industry information, an average discount of 46% has been applied to the published retail price of all compressors modelled.

Figure 27: 10 year net benefit for ten compressors, Australia 2009 (18hrs/day, 12 cents per kWh)



3.8.3 Conclusions

Based on this analysis it appears that there are clear financial benefits for end-users from switching to more efficient compressors. However, often it not the end-user that makes the selection of a compressor; typically contractors are used to purchase, supply and install equipment and hence compressors with the lowest capital costs are usually chosen. This instance of market failure sometimes referred to as the principle agent problem, will tend to favour the selection of lower efficiency equipment.

Even when end-users are sufficiently involved in purchasing equipment, the ability of large energy users to negotiate low energy costs from electricity suppliers can make the pay-back period for investment in energy saving technology unattractive.

Excessive noise is also sometimes cited as one disadvantage of the more efficient discus valve compressors compared to reed valve products. However the technical information for the two most popular market brands (see Table 12) suggests that any difference is negligible.

Table 12: Noise characteristics of reed and discus compressors

Manufacturers Model No's			Sound Pressure dBA @1m		
Cop. Model No Reed Valve	Bitz. Model No Reed Valve	Model No Discus Valve	Copeland Reed Valve	Bitzer Reed Valve	Copeland Discus Valve
D4SA-200X	4G-20.2Y	D4DA-200X	70	73*	72**
D4SH-250X	4H-25.2Y	D4DA-250X	70	70	71***

Notes:
* Bitzer Reed 1.4% higher than Discus
** Discus 2.9% higher than Copeland Reed
*** Discus 1.4% higher than Copeland and Bitzer Reed

Further, it should be noted that the largest users of this type of compressors are supermarket chains, which locate the compressors in plant rooms where noise is seldom a public or customer issue. Discus compressors are used in USA, Europe and NZ almost exclusively in supermarkets and other installations without the noise issue being perceived a problem.

With respect to Scroll compressors, one supermarket chain (Aldi) uses them exclusively in Australia and globally. A major manufacturer (Copeland) does offer noise attenuation covers for applications where noise could become an issue.

3.9 Australian energy efficiency policies and measurement standards

Australia does not have existing energy efficiency policies for compressor performance. Minimum energy performance standards for refrigerated display cabinets (referring to AS 1731 part 14) set maximum energy consumption levels for these types of commercial refrigeration equipment and therefore may encourage the use of more efficient compressors in self-contained display cabinets, in addition to improved insulation, lighting, design and other elements.

There is no specific Australian standard for the measurement of energy efficiency in compressors.

3.10 Overseas energy efficiency policies and measurement standards

3.10.1 Overseas energy efficiency policies

Under the Enhanced Capital Allowance scheme (ECA), the UK government has established a set of performance specifications for compressors, which serve as the main eligibility criteria for a capital allowance write-down. This measure is primarily aimed at the supermarket refrigeration segment.

Further details are included in Attachment 1.

3.10.2 Overseas measurement standards

3.10.2.1 EN 12900 (2005): "Refrigerant compressors - Rating conditions, tolerances and presentation of manufacturer's performance data".

This European Standard specifies the rating conditions, tolerances and the method of presenting manufacturer's data for positive displacement refrigerant compressors. These include single stage compressors and single and two stage compressors using a means of liquid sub-cooling. This is required so that a comparison of different refrigerant compressors can be made.

EN 12900 specifies standard reference points for reporting of the performance of the compressor under test, as shown in Table 13.

Table 13: EN 12900 (2005) Standard reference points

	Compressor Applications			
	High evaporator temperature	Medium evaporator temperature	Low evaporator temperature	Household and similar refrigerators/freezers
Evaporating temperature (°C) at suction dew point	+5	-10	-35	-25
Condensing temperature (°C) at discharge dew point	+50	+45	+40	+55
Suction vapour temperature (°C) or superheat (K)	+20 10 or 5[a]	+20 10 or 5[a]	+20 10 or 5[a]	+32
Sub-cooling (K)	0	0	0	0

[a] For R-717

As a result of tests, the following items are required to be reported:

- Refrigerating capacity, in values able to be read to an accuracy of ± 2 %;
- Absorbed power, in values able to be read to an accuracy of ± 2 %;
- Evaporating temperatures at suction dew point with intervals not greater than 5 K;
- Condensing temperatures at discharge dew point with intervals not greater than 10 K;
- For compressors using a specific means of liquid sub-cooling, the temperature of the liquid leaving the sub-cooler must be specified.

3.10.2.2 EN13771-1 (2003): "COMPRESSORS AND CONDENSING UNITS FOR REFRIGERATION – PERFORMANCE TESTING AND TEST METHODS - PART 1: REFRIGERANT COMPRESSORS"

This part of the European Standard applies only to refrigerant compressors and describes a number of selected performance test methods. These methods provide sufficiently accurate results for the determination of the refrigerating capacity, power absorbed, refrigerant mass flow, isentropic efficiency and the coefficient of performance.

This standard also defines the coefficient of performance (COP) as the ratio of the refrigerating capacity to the power absorbed (no units).

3.10.2.3 ANSI/ASHRAE Standard 23-2005 "Methods of Testing for Rating Positive Displacement Refrigerant Compressors and Condensing Units".

This standard applies to the methods of testing for rating single-stage positive-displacement refrigerant compressors and condensing units that (a) do not have liquid injection and (b) are operated at subcritical (saturated) temperatures of the refrigerant. It also applies to the methods of testing for rating single-stage positive-displacement refrigerant compressors and condensing units that (a) incorporate liquid injection that is controlled by a steady flow rate method and (b) are operated at subcritical (saturated) temperatures of the refrigerant.

3.10.2.4 Referenced sources

The refrigerant properties used in the calculation of compressor performance may be obtained from:

- The US National Institute of Standards & Technology (NIST) Standard Reference Database 23 Thermodynamic and Transport Properties of Refrigerants and Refrigerant Mixtures. Database: Version 6.0 or later. See http://fluidproperties.nist.gov/ or http://www.nist.gov/;
- The ASERCOM properties database as defined in the ASERCOM Compressor Certification scheme, which is based closely on the NIST database (see http://www.asercom.org/) (see Attachment 2).

3.10.2.5 Air-cooled condensing units

A related test method is prEN13771-2: "Performance testing and test methods", which provides a COP calculation method but is currently under review and further development.

3.10.2.6 Voluntary certification

The Association of European Refrigeration Compressor and Controls Manufacturers (ASERCOM) manage a voluntary certification program to verify the performance of compressors (see Attachment 2).

There are currently 517 certified compressors from the following member companies:

- ACC Appliances Components Companies;
- Arcelik;
- Arctic Circle;
- Bitzer;
- Bock;
- Cubigel Compressors;
- Danfoss Compressors;
- Danfoss Commercial Compressors;
- Embraco Europe;
- Emerson Climate Technologies;
- Frascold;
- Frigopol;
- Grasso;
- Ingersoll Rand (Thermoking);
- Johnson Controls International;
- Officine Mario Dorin;
- Tecumseh Europe.

3.11 Conclusions and recommendations

3.11.1 The case for policies to stimulate energy efficiency

This review of the potential for improving the energy efficiency of compressors used in refrigeration strongly indicates that there are significant potential electricity and greenhouse gas savings to be made from moving the market towards the purchase of products that are currently available in the Australian market. Analysis also indicates that this will bring net financial benefits to end-users that either purchase separate compressors or refrigeration equipment that contains compressors.

A further advantage of the introduction of policy measures designed to increase the efficiency of compressors across all refrigeration applications is that it effectively targets the most significant single component, in terms of electricity consumption. Since the numbers of applications are numerous and dispersed, this has the potential to achieve a similar or better outcome as many separate policies focused on discreet applications. As such an effective horizontal policy measure can reduce the policy burden on governments and industry.

3.11.2 Appropriate types of policies

The general types of policies that may be considered by governments in this case include:

- Industry training;
- Customer information (e.g. via a website);
- Voluntary energy labelling;
- Mandatory energy labelling;
- Minimum energy performance standards;
- Market based incentives.

Table 14: Aims and attributes of policy options

Policy Measure	Policy Aim	Pros	Cons
Industry training	Change industry practices such as over-sizing. Pass on best practice to customers.	Potential long-lasting impact. Flow-on effect through the industry brought about by competition	Doesn't address customer preferences directly. Uncertainty of outcomes. Slow-acting
Customer information	To highlight to customers how to specify the best performing products and practices	Relatively simple and inexpensive. Can focus on good design and installation practices.	Targeting difficult because of quantity and diversity of potential users Uncertainty of outcomes.
Voluntary labelling	To highlight to customers the best performance products on the market	Relatively simple and inexpensive.	Relies upon consumer awareness of the label. Requires industry support. Does not address first-cost issue Uncertainty of outcomes.
Mandatory labelling	To enable customers to compare the energy performance of different products	Provides more information than other similar options.	Relies upon consumer awareness of the label. More expensive than other information options. Does not address first-cost issue Uncertainty of outcomes
Minimum energy performance standards	To remove the worst performing products from the market.	Promotes competition on a level playing field. Proven to be effective. Certainty of outcomes.	Probably the most expensive option.
Market based incentives	To reduce the capital cost of an efficient product - typically to make it cost-effective	Tackles increased upfront investment Attracts attention	May reduce split incentive issues Uncertainty of outcomes Can be expensive

While all of these policy options have merits, the significant presence split-incentives in the market that minimum energy performance standards will be the most effective, providing results more quickly and with a greater degree of certainty than the other policy options identified above.

The use of market based incentives to promote increased investment also warrants further investigation, since these will help to draw attention to the energy efficiency opportunities and require the development of a list of eligible technologies.

For compressors, it is unlikely that a physical label will be useful to customers; however there is a case for providing information on best practice in selecting sizes and specifying products.

The impact of industry training is likely to take a long period of time to have a significant impact on energy consumption, however it should be considered alongside general efforts to improve the skill-base in Australia and orientate it towards more energy efficient outcomes.

3.11.3 Outline recommendations

- Minimum energy performance standards (MEPS) should be introduced for all compressors with a displacement between 1.4 to 836m^3/hr offered for sale in Australia and New Zealand at the earliest opportunity that allows for reasonable adjustment by suppliers and customers. It is considered likely that this might be towards the end of 2012;
- MEPS levels should be based on the calculated coefficient of performance (COP) based on input power and the refrigerating capacity of the compressor tested according to EN 21900 (2005) and EN 13771-1 (2003), at +5°C[12] (50°C[13]) for medium temperature applications, and at -25°C (55°C) for low temperature applications;
- All compressors offered for sale in Australia and New Zealand should be required to be registered in a similar manner to other products regulated for energy efficiency in these countries. It should be sufficient for the registration of technical performance to be made on the basis of a self-declaration based on in-house tests or on a rating undertaken by ASERCOM;
- In addition to the establishment of minimum energy performance levels, it is recommended that high efficiency performance standards (HEPS) COP levels should also be set to reflect the best performing products in the market. Further investigation by government and industry into the most effective means of assisting the promotion of these products is recommended.

3.11.4 MEPS and high efficiency levels for medium temperature applications

Minimum energy performance standards are intended to remove the worst performing products from the market while at the same time maintaining reasonable customer choice and not increasing total costs over the life-time of the product. Customer choice may be maintained by the development of new or re-engineered products to meet MEPS.

In most cases, MEPS are designed to be technologically neutral, i.e. they set an energy performance threshold for all technologies providing equivalent energy services. A similar approach has been suggested in the following approach which sets a threshold COP level applicable to all technologies in the market.

Figure 28 illustrates how this proposal works for medium temperature compressors. The figure plots the COP rating of 120 compressors models with significant market share together with the proposed MEPS level, illustrated by the solid red line. A designated 'high efficiency performance' level (HEPS) is shown by the sold yellow line. In this case the thresholds are defined by the following equations:

MEPS: Minimum COP = $1 + (1.85 * \Phi_0 / (\Phi_0 + 2600))$

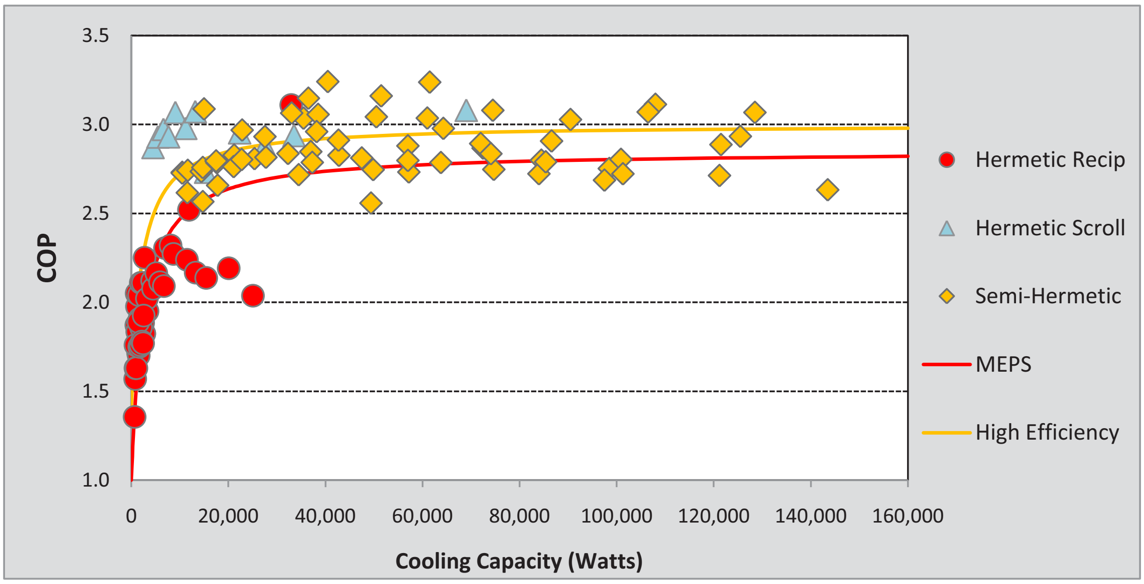
High Efficiency: Minimum COP = $1.4 + (1.60 * \Phi_0 / (\Phi_0 + 2100))$

[12] Evaporating temperature (°C) at suction dew point.
[13] Condensing temperature (°C) at discharge dew point.

Where:

Φ_0 = Cooling Capacity (Watts)

Figure 28: MEPS & HEPS levels for medium temperature compressors



At these levels, and based on available product data, approximately 70% of compressors would pass MEPS and around 25% would exceed HEPS. These rates vary by size category and the shares of compressors within common bins are shown in Figure 29 and

Figure 30.

Figure 29: Pass/Fail rate for MEPS by Bin (medium temperature)

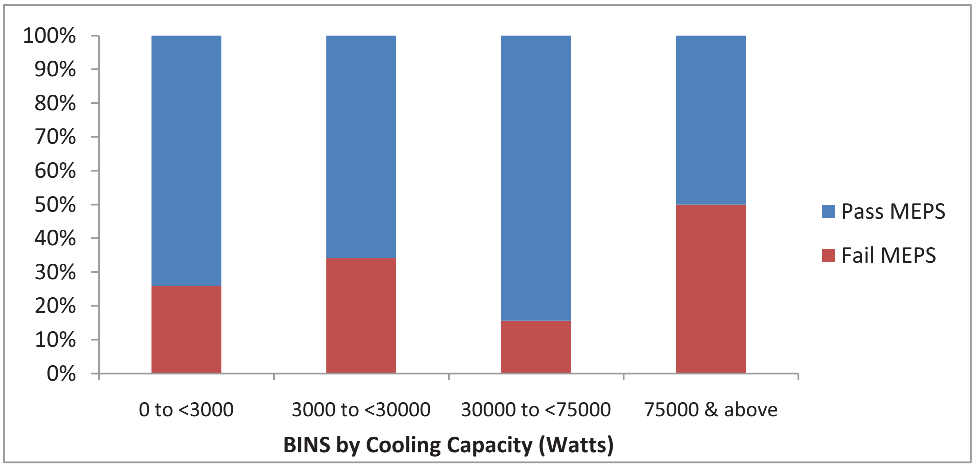
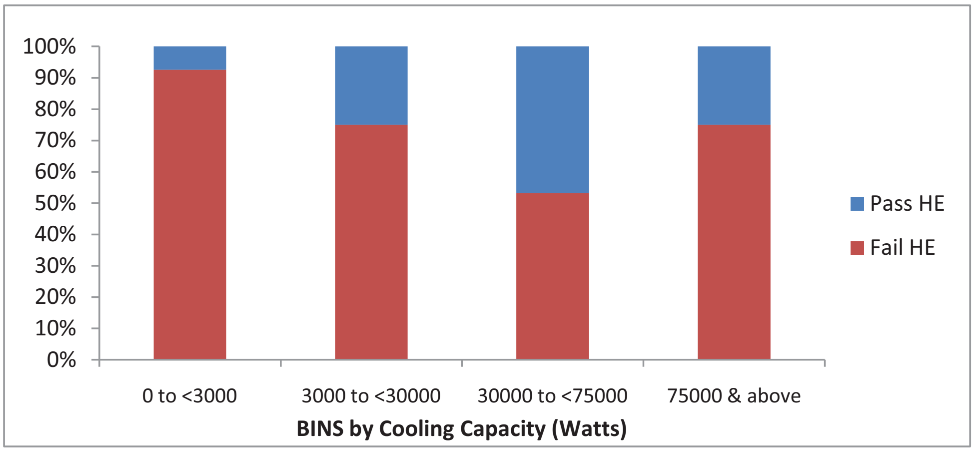


Figure 30: Pass/Fail rate for HEPS by Bin (medium temperature)



3.11.5 Options for MEPS and high efficiency levels for low temperature applications

Figure 31 illustrates how this proposal works for low temperature cases, with the red line indicating the MEPS level. In this case the threshold levels are defined by the following equations:

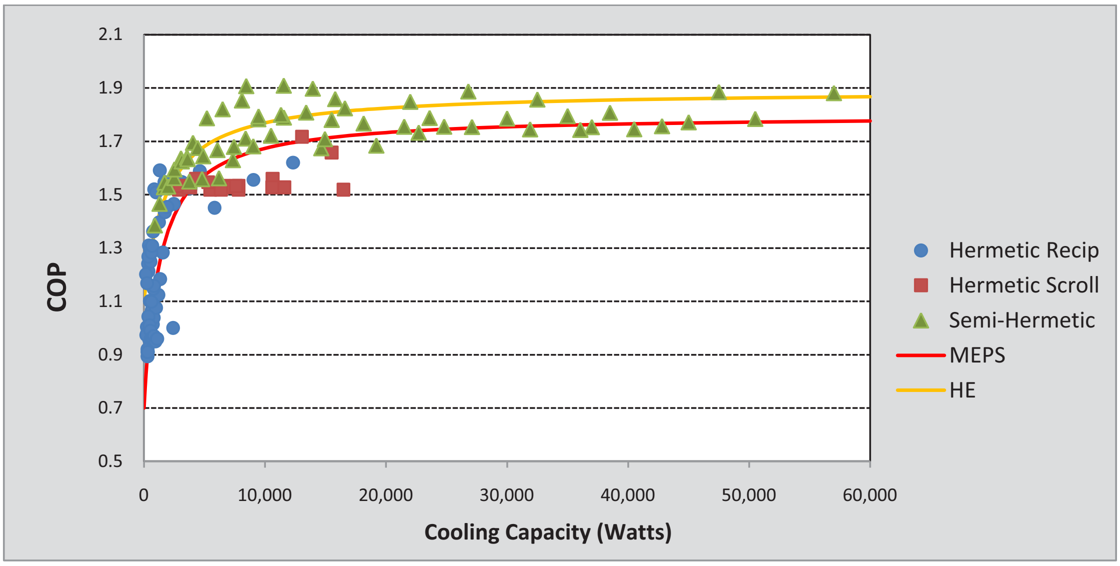
MEPS: Minimum COP = $0.7 + (1.10 * \Phi_0 / (\Phi_0 + 1300))$

High Efficiency: Minimum COP = $1.1 + (0.79 * \Phi_0 / (\Phi_0 + 1800))$

<u>Where:</u>

Φ_0 = Cooling Capacity (Watts)

Figure 31: Option 1 – MEPS & HEPS levels for low temperature compressors



At these levels, and based on available product data, approximately 70% of compressors would pass MEPS and around 30% would exceed HEPS. These rates vary by size category and the shares of compressors within common bins are shown in Figure 32 and Figure 33.

Figure 32: Option 1 – Pass/Fail rate for MEPS by Bin (low temperature)

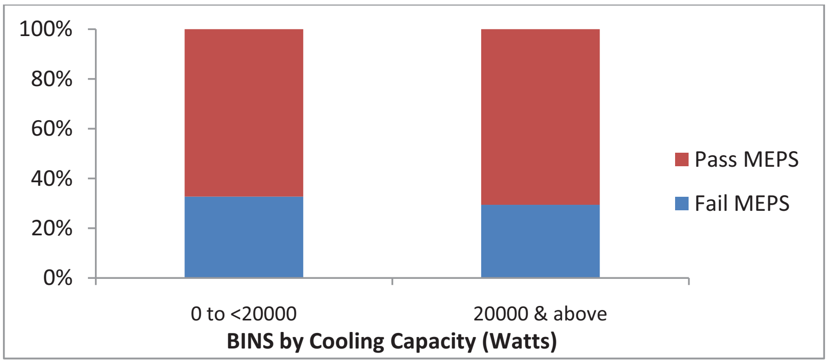
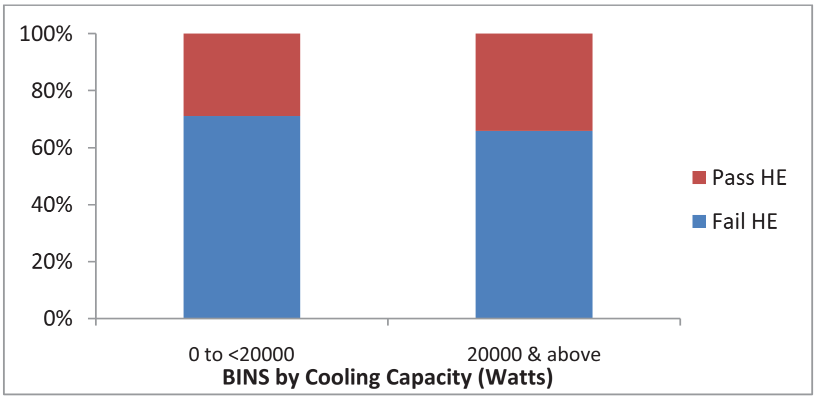


Figure 33: Option 1 – Pass/Fail rate for HEPS by Bin (low temperature)



3.11.6 Further issues

Currently the facilities for undertaking tests to EN12900 do not exist in Australia or New Zealand for the full range of compressors proposed to be covered by MEPS. Therefore E3 will need to investigate the alternative options for undertaking check tests, probably through arrangements with overseas laboratories with oversight by independent experts. Although suitable laboratories exist in the USA, Europe, Japan and China, further investigations need to be undertaken into the capacity, expertise and cost of using these facilities. A ring-test of a small sample of compressor models might form a component of this decision-making process in order to determine levels of expertise and the variation in laboratory results.

3.12 References

Policy brief UK Govt	Improving the energy performance of commercial Refrigeration products-July 2008 www.defra.gov.uk
Emerson Climate Technologies	Status of USA energy regulation for Commercial Refrigeration – January 2008
Blackmer	Blackmer Screw Technologies
Francois Billiard – IIR	Refrigerating Equipment, Energy Efficiency and Refrigerants
Jean-Luc –IIR	Improving Energy Efficiency in Refrigeration

Attachment 1: ECA ENERGY TECHNOLOGY CRITERIA LIST 2008 – REFRIGERATION EQUIPMENT

Refrigeration compressors
Date added to ETL 2002 (Revised 2008).

Definition of technology

Refrigeration compressors are products that are specifically designed to raise the pressure, temperature and energy level of a refrigerant vapour by mechanical means as part of a standard "vapour-compression" refrigeration cycle.

Economiser packages consist of a refrigeration compressor, a heat exchanger that is used to increase refrigerant sub-cooling and compression efficiency, and an expansion device.

Technology description

Refrigeration compressors are at the heart of every refrigeration system that employs a vapour compression refrigeration cycle. They range in size from those used in refrigerated display cabinets used in shops and supermarkets, to those used in large industrial refrigeration systems in breweries.

Refrigeration compressors are available in a range of different designs and efficiencies, and can be manufactured as fully hermetic, semi-hemetic or open products. The ECA scheme aims to encourage the purchase of the higher efficiency products.

The categories of refrigeration compressor and economiser package covered are:

- High temperature with R407C;
- Medium temperature with R404A;
- Low temperature with R404A.

These categories are defined in terms of the specific refrigerant and the product performance at a particular temperature rating point. Products may be submitted under more than one category.

Investments in refrigeration compressors can only qualify for Enhanced Capital Allowances if the specific product is named on the Energy Technology Product List. To be eligible for inclusion on the Energy Technology Product List, products must meet the eligibility criteria as set out below.

Eligibility criteria

To be eligible, products must:

- Use the refrigerant specified by the product category;
- Be either a refrigeration compressor or an economiser package;
- Incorporate a positive displacement type, hermetic or semi hermetic compressor (with integral electric motor) that has a displacement greater than 9 cubic metres per hour;
- Be subject to quality assurance procedures that ensure consistency of performance between one production item and any other.

Performance criteria

Products must have a coefficient of performance (COP) that is greater than the values shown in Table 15 below at the specified UK rating points.

Table 15: Performance thresholds for refrigeration compressors at the UK rating points

Category	Evaporating Temperature	Condensing temperature	Compressor suction gas temperature	Liquid sub-cooling	COP threshold
High temperature with R407C	+5°C	35°C	20°C	0 K	>5.20
Medium Temperature with R404A	-10°C	30°C	20°C	0 K	>3.36
Low Temperature with R404A	-35°C	25°C	20°C	0 K	>1.94

">" means "greater than"

Where COP must be determined in the manner specified in EN12900:2005 "Refrigerant compressors – Rating conditions, tolerances and presentation of manufacturer's performance data".

For the avoidance of doubt test data should be presented to 2 decimal places. As an example, a product in the high temperature with R407C category with a COP of 5.20 would be deemed to be a fail.

Required test procedures

All products must be tested in accordance with one of the following standards:

- BS EN13771-1:2003 "Compressor and condensing units for refrigeration. Performance testing and test methods. Part 1: Refrigerant compressors";
- ANSI/ASHRAE Standard 23-2005 "Methods of Testing for Rating Positive Displacement Refrigerant Compressors and Condensing Units".

The refrigerant properties used in the analysis of compressor performance must be obtained from one of the following sources:

- The US National Institute of Standards & Technology (NIST) Standard Reference Database 23 Thermodynamic and Transport Properties of Refrigerants and Refrigerant Mixtures Database: Version 6.0 or later. See http://fluidproperties.nist.gov/ or http://www.nist.gov/;
- The ASERCOM properties database as defined in the ASERCOM Compressor Certification scheme, which is based closely on the NIST database (see http://www.asercom.org/).

For the high temperature category only, data for a suction gas temperature of 20°C may be obtained by the thermodynamic translation of data physically tested at 10K superheat.

A test report must be submitted in accordance with the formats specified in EN13771-1:2003.

This must include a statement of achieved performance at the required UK rating point. Data on refrigerating capacity and COP at the appropriate standard rating point specified in EN12900:2005 must also be submitted for the purposes of data verification.

If the test report has not been prepared by an independent body, then evidence must be provided that a representative sample of product test data has been independently verified or cross-checked.

Products that depend on an external motor for compressor operation (i.e. 'open' type compressors) are not eligible.

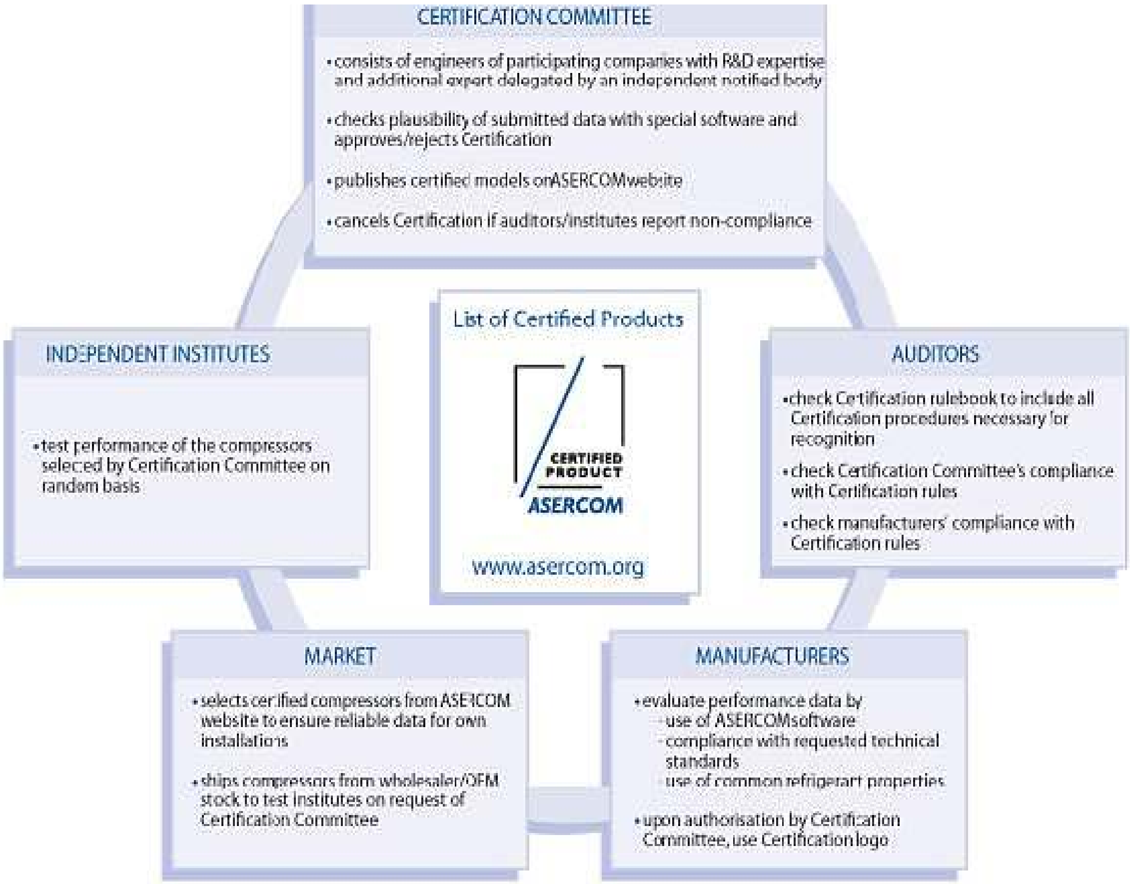
Scope of claim

Expenditure on the provision of plant and machinery can include not only the actual costs of buying the equipment, but other direct costs such as the transport of the equipment to site, and some of the direct costs of installation. Clarity on the eligibility of direct costs is available from HMRC.

Attachment 2: ASERCOM

ASERCOM[14] is voluntary certification program described in the following Figure (www.**asercom**.org).

Figure 34: Flow chart defines how the ASCERCOM certification program operates.



[14] ASCERCOM is Association of European Refrigeration Compressor and Controls Manufacturers.

4 Fan Motors

4.1 Description of technology

Electric fan motors consists of two basic parts, an outside stationary stator having coils supplied with AC or DC current to produce a rotating field, with a rotor inside attached to the output shaft with a fan blade attached.

The energy efficiency of a motor is measured in percentage terms by measuring power output at the shaft divided by power input.

$$\textbf{Motor Efficiency (\%)} = \frac{\textit{Power Output (Watts)}}{\textit{Power Input (Watts)}}$$

Fan motors of between 5 Watts and 2,000 Watts are used throughout the non-domestic refrigeration sector, consuming an estimated 33% of all energy used in non-domestic refrigeration based on modelling from Cold Hard Facts (ES, 2007).

The use of electrically driven fans in non-domestic refrigeration is integral to the correct design and efficient functioning of the refrigeration system, since they ensure that the correct storage temperature of refrigerated products is maintained. Fans circulate air over heat exchangers, known as the evaporator and condenser, into the cold storage space and also discharge heat from the condenser to an external space.

Electric motor technology has advanced continuously over the last two decades continuously. AC induction motors comprise the majority of products sold in the industrial market and their energy performance has been improved through better design, more precise production and use of more conductive material.

Fan blade technology has also improved over the last two decades driven by the air conditioning industry pursuit for better motor/fan efficiency and lower air noise levels.

The most common fan motors used in fans systems for non-domestic refrigeration applications are as follows:

- Single-phase small fan motors – mostly of the shaded-pole (SP) type;
- Single and three-phase fan motors - external rotor (ERM) fan assembly type;
- Three-phase totally enclosed fan-cooled (TEFC) – fitted with external fan.

4.1.1 Shaded-pole single-phase fan motors

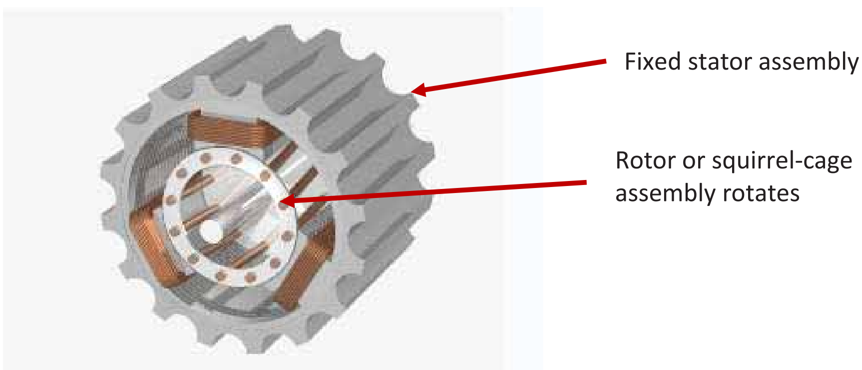
The shaded-pole motor is a type of AC single-phase induction motor. As in other induction motors, the rotating part is a squirrel-cage rotor. All single-phase motors require a means of producing a rotating magnetic field for starting. In the shaded-pole type, a part of the face of each field pole carries a copper ring called a shading coil. Currents in this coil delay the phase of magnetic flux in that part of the pole sufficiently to provide a rotating field. The effect produces a low starting torque compared to other classes of single-phase motors.

These motors have one winding and no capacitor or starting switch, making them economical and reliable. Since their starting torque is low, they are best suited to driving fans or other loads that are easily started. Moreover, they are compatible with triac-based variable-speed controls, which often are used with fans. They are built in power sizes of about 5 to 70 watts output. While these motors have been the most prolific in use they are now considered very inefficient compared to other new types, like electronically commutated (EC) motors of similar capacities.

Illustrations of shaded-pole motors are provided in Figure 35 and Figure 36.

Figure 35: Shaded-pole motors

Figure 36: Cut-away of stator and rotor of shaded-pole motor



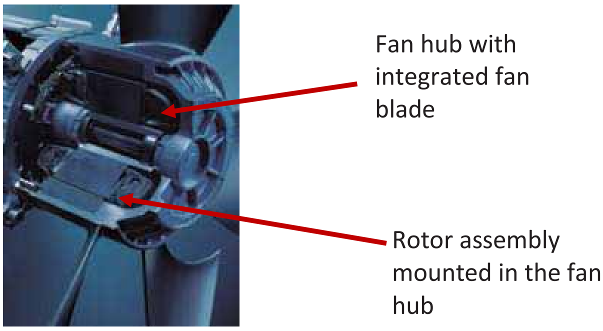
4.1.2 External rotor (ERM) fan assembly: single and three-phase fan motors

External rotor motors are another version of AC induction motor. In this type of induction motors the wound stator is fixed and the rotor assembly rotates externally around the stator. When combined with a fan blade the rotor is integrated into the fan blade forming the hub, resulting in better cooling of the motor by the airflow passing over it and improved motor efficiency. Figure 37 and Figure 38 shows the construction of this type of motor.

Figure 37: Typical single and three-phase external rotor motor /fan/guard assembly

Source: ebm-papst

Figure 38: Cut-away of hub and fan, external rotor motor assembly



Source: ebm-papst

4.1.3 Permanent split capacitor motor (PSC)

Permanent split capacitor motors are not often used in non-domestic refrigeration; they are mostly used in residential air conditioners and other household appliances. Also known as a capacitor start and run motors, PSC motors have the start windings permanently connected to the power source through a capacitor along with the run windings.

A capacitor typically ranging from 3 to 25 microfarads is connected in series with the start windings and remains in the circuit during the run cycle. The start windings and run windings are identical in this motor.

These motors are typically more efficient than the same size shaded-pole motors due to the continuous capacitor assistance but in most cases operate at less than full load, which reduces the efficiency of the motor installed.

Figure 39: Typical PSC appliance size motors

Source: Wikipedia

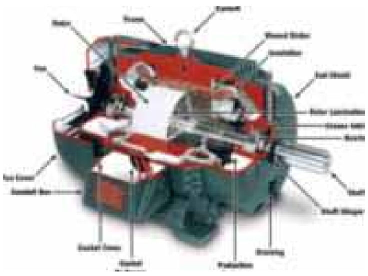
4.1.4 Totally enclosed fan-cooled (TEFC) fitted with external fan: three-phase

Totally enclosed, fan-cooled (TEFC) refers to an industrial three-phase AC induction electric motor fitted with an external fan blade to circulate surrounding air over the motor as well as providing air movement for various non-domestic refrigeration applications. Typically these three-phase motors have relatively high efficiency levels in the 90-95% range. Figure 40 and Figure 41 illustrate this motor type.

Figure 40: Typical TEFC motor

Source: Wikipedia

Figure 41: Cut-away TEFC motor



Source: Wikipedia

4.1.5 Electronically commutated motors (EC or ECM)

A brushless EC motor is a synchronous electric motor which is powered by direct-current electricity (DC) which has an electronically controlled commutation system, instead of a mechanical commutation system based on brushes. In such motors, current and torque, voltage and rpm are linearly related.

In EC motors, the electromagnets do not move; instead, the permanent magnets rotate and the armature remains static. In order to do this, the brush-system/commutator assembly is replaced by an electronic controller. The controller performs the same power distribution found in a brushed DC motor, but using a solid-state circuit rather than a commutator/brush system.

EC motors offer several advantages, including higher efficiency and reliability, reduced noise, longer life-time (no brush erosion), elimination of ionizing sparks from the commutator, more power, and overall reduction of electromagnetic interference (EMI). With no windings on the rotor, they are not subjected to centrifugal forces, and because the electromagnets are attached to the casing, the electromagnets can be cooled by conduction, requiring no airflow inside the motor for cooling. This in turn means that the motor's internals can be entirely enclosed and protected from dirt or other foreign matter.

EC motors require electronic speed controllers to run. In small single-phase sizes up to 70 Watts they are most often built into the motors electronics. For larger sizes, both single and three-phase, speed controllers are typically often separate units and can control more than one EC motor.

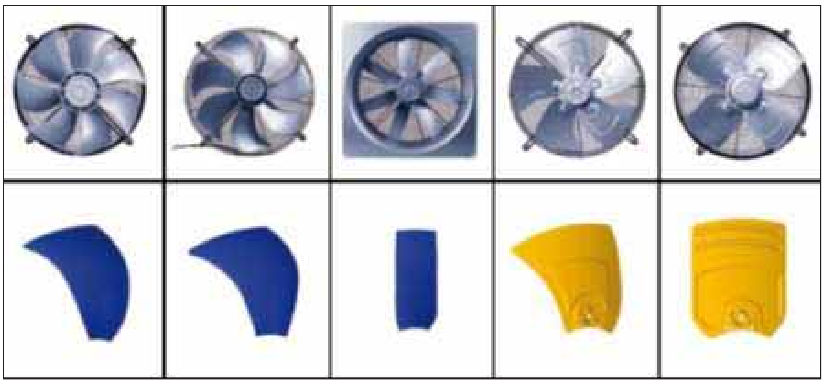
Figure 42: A typical EC motor and blade assembly

Source: ebm-papst

4.1.6 Fan blade technology

To improve fan assembly efficiencies, manufacturers offer a wide choice for matching various fan designs with different application (as shown in Figure 43). Manufacturers provide detailed application curves for accurate selection criteria.

Figure 43: Detailing various fan blade designs for optimizing motor / fan efficiencies



Sickle blade high efficiency fan and low noise	Sickle blade high air volume capability	Axial fan, high efficiency and high air volume	Sickle blade axial fan	Economical flat axial Blade

Source: Ziehl-Abegg

4.1.7 Types of fan motors and configurations

Table 16 below outlines the full range of motors used in non-domestic refrigeration and their relative shaft efficiency level ranges.

Table 16: Typical efficiency ranges for fan motor types

Motor Type	Power Supply		Capacity Range	Efficiency (%)[2]
Shaded-pole	Single-Phase	240V, 50Hz	5 to 70W	20% to 30%
EC[3]: small				60% to 70%
PSC[4]			30 to 1,00W	40% to 60%
EC: medium			70W to 770W	90% to 95%
External rotor				40% to 60%
TEFC[5]	Three-Phase	415V, 50Hz	500W to 2,000W	80% to 85%
EC				90% to 95%
External rotor			500W to 2,000W	75% to 85%

Source: ebm-papst and Ziehl-Abegg

Notes:

[2] Shaft power efficiency rating without blade

[3] EC is Electronically commutated motors

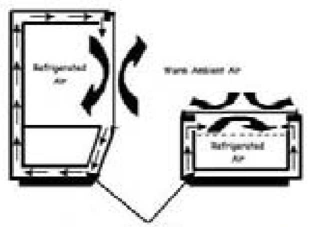
[4] PSC is Permanent split capacitor motor

[5] TEFC is Totally enclosed fan-cooled

4.2 Fan motor uses in non-domestic refrigeration

Table 17 summarises the most popular applications for the different types of fan assemblies.

Table 17: Non-domestic refrigeration applications for fan motors

Application	Location	Motor Type	
Supermarket display cases	Evaporator	mostly single-phase shaded-pole	 Fan Motors circulate air within a Supermarket display cases
Self Contained refrigerated display cases, vending machines & refrigerated storage cabinets	Evaporator & Condenser	mostly single-phase shaded-pole	
Walk-In coolrooms	Evaporator	Mostly single-phase external rotor motor and blade assembly	
Air-cooled condensing units	Condenser	Mostly single-phase, but some three-phase, external rotor motor and blade assembly	
Air-cooled condensers, remote type	Condenser	Mostly single-phase, but some three-phase, external rotor motor and blade assembly	
Evaporative cooling towers	Condenser	Mostly three-phase, external rotor motor and blade assembly and some TEFC type	
Blast coolers & freezers	Evaporator & Condenser	Mostly single-phase, but some three-phase, external rotor motor and blade assembly	

Source: Wikipedia, Orford, Bitzer

4.3 Market profile

4.3.1 Sales

The number of fans in the installed base of non-domestic refrigeration in Australia is estimated to be 6.6 million fans with an average life-time of 7 years, therefore the annual sales are approximately 0.94 million fans. With the expected growth rate of non-domestic refrigeration of 2% to 3% per annum these sales levels are expected to be continued until small shaded-pole motors are replaced with more reliable EC types coming onto the market now.

Industry sources suggest that typical life-times of the various motors types are as detailed below in Table 18.

Table 18: Typical motor life-times

Fan Motor Type	Average Life-time expectancy
Shaded-pole single-phase	3.5 Years
External rotor single-phase	5.0 Years
External rotor three-phase	5.0 Years
EC single and three-phase	7.0 Years

Motor failure is generally the result of the windings overheating caused by bearing failure, particularly in the case of smaller shaded-pole motors. As shown in Figure 44 and Figure 45, bearing lifetime is related to temperature, and therefore the cooler a motor runs the longer the life of the bearings and the motor.

EC/ECM motors inherently run cooler than other motor types and thus will have longer bearing life, although the same temperature factors then affect the electronics, so ECMs used as condenser fan motors may have limited life spans.

It should be noted that a lack of maintenance also contributes to bearing failure, through the build up of dust, dirt and lint that can cause the bearing to dry out by 'wicking' oil from the bearings. A build up of dust and dirt or physical damage can cause the fan blades to run out of true or balance and thus accelerate bearing failure.

Figure 44: Sleeve bearing motor life

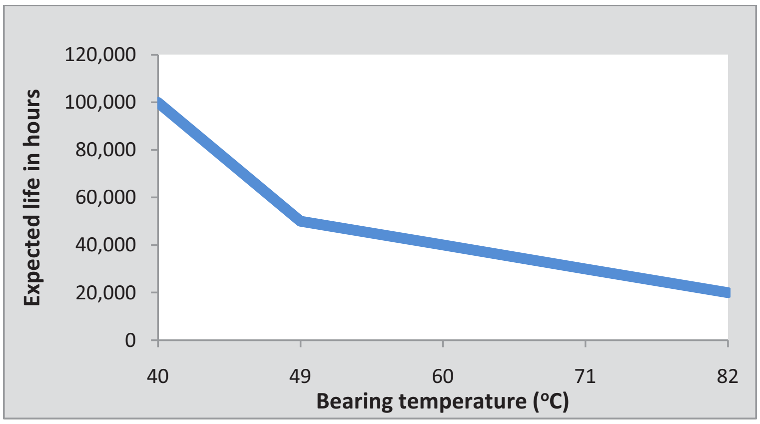
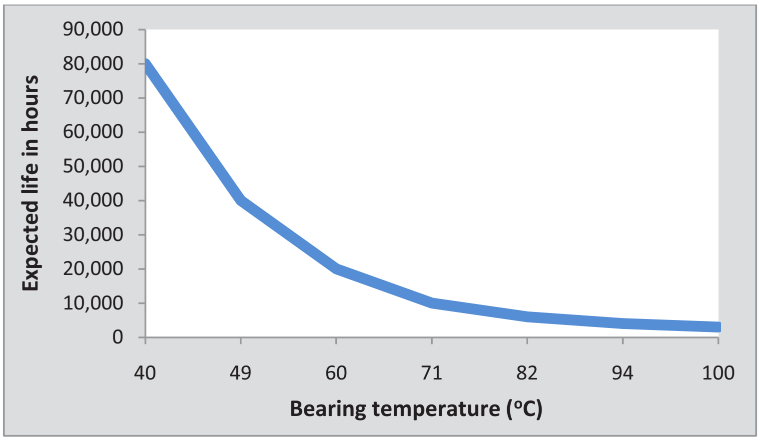


Figure 45: Ball bearing motor life



4.3.2 Stock

The current stock by type of the most common motors used on various products as described above is detailed in Table 19.

Table 19: Estimates stock of fan motors used in non-domestic refrigeration, Australia 2008

Fan Motor Type	Number in installed base	% of Total
Shaded-pole single-phase	2,446,200	37%
External rotor single-phase	2,002,300	30%
External rotor three-phase	2,190,880	33%
Total	6,639,380	100%

Source: Based on modelling from CHF database.

4.3.3 Suppliers

All fan motors used in non-domestic refrigeration are now imported; the following are major suppliers:

- Ebm-papst Australia Pty Ltd;
- Torin Industries Pty Ltd;
- Ziehl-Abegg Australia Pty Ltd;
- Wellington Drive Technologies Ltd (NZ).

As shown in Table 20 , the value of motors imported into Australia and likely be used in the non-domestic refrigeration sector has more than doubled in the past ten years.

Table 20: Value of motor imports into Australia, 1999-2008 (AUD$ million)

Type	1999 AUD$M	2003 AUD$M	2008 AUD$M
AC Motors single-phase up to 37.5W	$38	$75	$70
AC Motors, single-phase less than 380W	$10	$15	$32
AC Motors, multi-phase to 750W	$7	$10	$17
AC Motors, multi-phase less than 3,000W	$9	$11	$16
Total	**$64**	**$111**	**$135**
% Shift on base year	**100%**	**158%**	**211%**

Source: ABS, 2009

The leading countries of origin have changed significantly over the 10 year study period as shown in Table 21 and Table 22; however the United States and Europe remain the top two regional suppliers from 1999 to 2008.

The most notable change has been the growth of imports from China, rising to number two ranking in 2008 from a very low base in 1999 and 2003.

Table 21: Country of origin, fan motor imports into Australia, 1999-2008

1999		2003		2008	
Country of Origin	**$A Mil. Import Value**	**Country of Origin**	**AUD$ Mil. Import Value**	**Country of Origin**	**AUD$ Mil. Import Value**
Germany	$11.53	USA	$18.30	USA	$29.60
USA	$10.48	Japan	$10.50	China	$22.66
Vietnam	$6.84	Vietnam	$10.50	Thailand	$17.90
France	$3.10	Italy	$6.40	Germany	$10.14
Italy	$2.93	France	$4.05	France	$8.96
UK	$2.63	Germany	$2.31	Italy	$1.87
		Thailand	$1.98		
		China	$1.54		
		UK	$1.10		
Total	**$37.51**	**Total**	**$56.68**	**Total**	**$91.13**
% of Total Imports	**59%**	**% of Total Imports**	**51%**	**% of Total Imports**	**68%**

Source: ABS, 2009

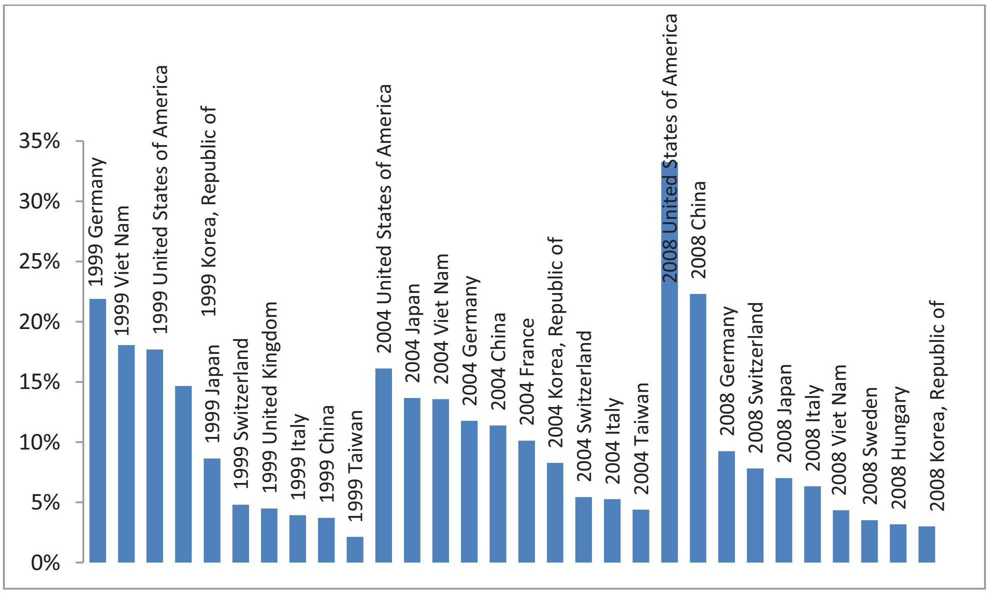
Table 22: Region of origin, fan motor imports into Australia, 1999-2008

Region of Origin	$A Mil. Import Value	$A Mil. Import Value	$A Mil. Import Value
Europe incl. UK	$20.19	$13.86	$20.97
Americas	$10.48	$18.30	$29.60
SEA	$6.84	$12.48	$17.90
Japan	-	$10.50	-
China	-	$1.54	$22.66
Totals	**$37.51**	**$56.68**	**$91.13**
% of Total Imports	**59%**	**51%**	**68%**

Source: ABS, 2009

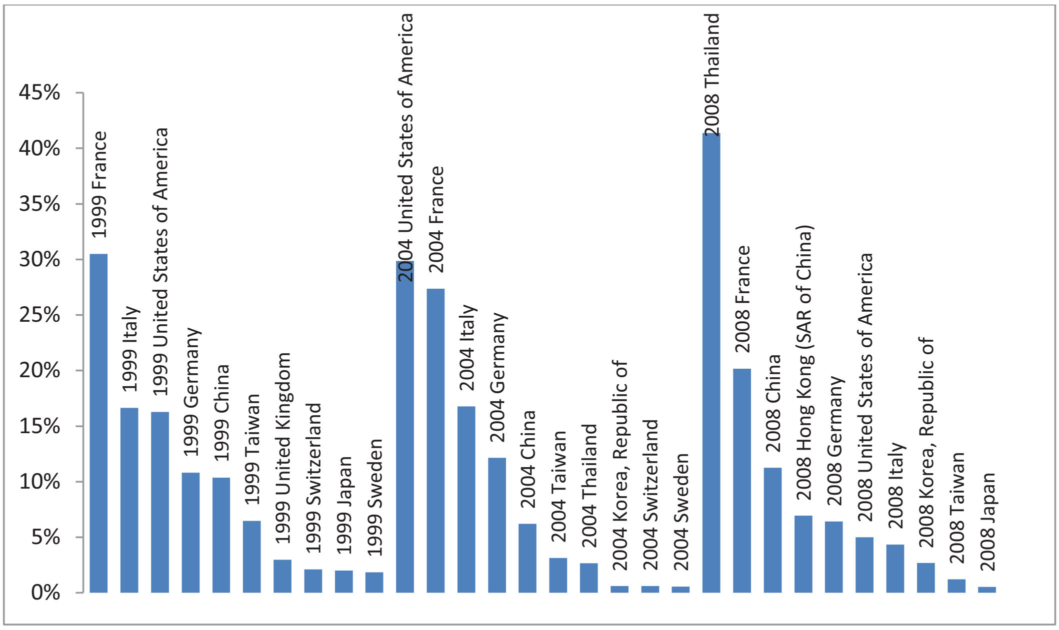
Figure 46 to Figure 49 shows the import data as a percentage of total imports by country of origin in the motor types likely to be used in non-domestic refrigeration.

Figure 46: AC motors not exceeding 37.5 W, imported into Australia 1999-2008



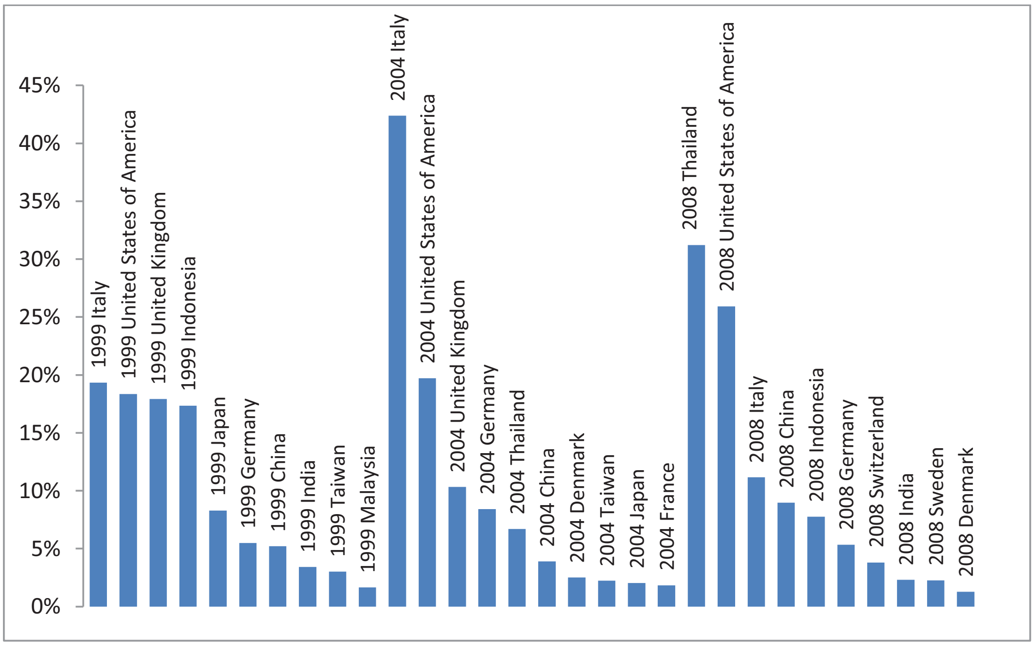
Source: ABS, 2009

Figure 47: AC single-phase motors not exceeding 380W, imported into Australia 1999-2008



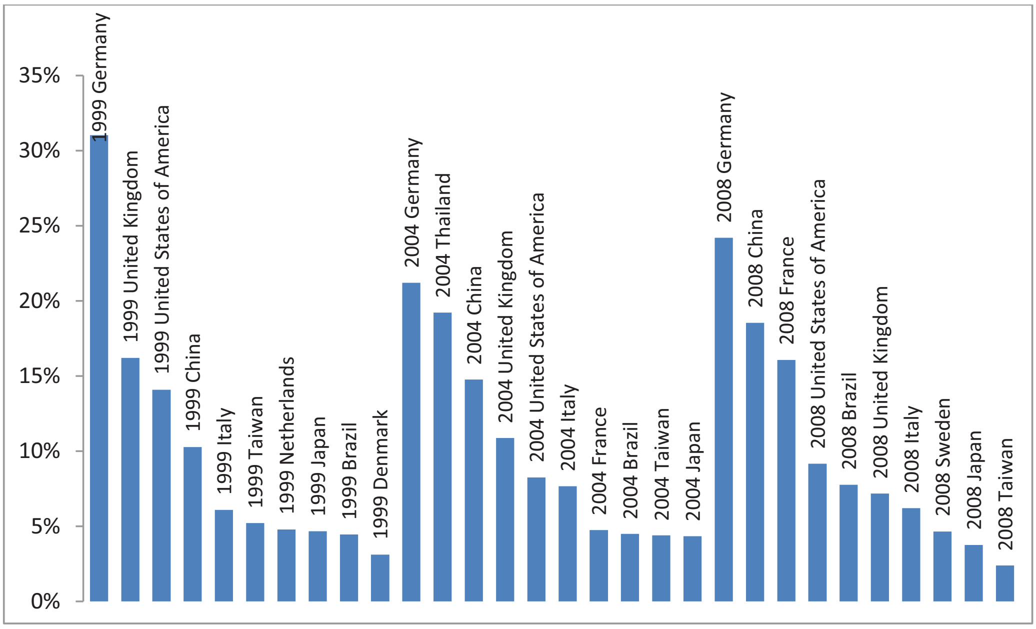
Source: ABS, 2009

Figure 48: AC single-phase motors not exceeding 746 W, imported into Australia 1999-2008



Source: ABS, 2009

Figure 49: AC multi-phase motors not exceeding 750 W, imported into Australia 1999-2008



Source: ABS, 2009

As no local manufacture now exists for fan motors used in non-domestic refrigeration, all fan motors sold as individual items in Australia are imported by either the local office of the overseas manufacturer or agents, or industry wholesalers. The sale of motors without fan blades is common for shaded-pole types, but external rotor motors tend to be mostly sold to OEM's with specifically selected fan blades and are sold as an assembly with motor, blade and fan guard as shown in Figure 43 earlier.

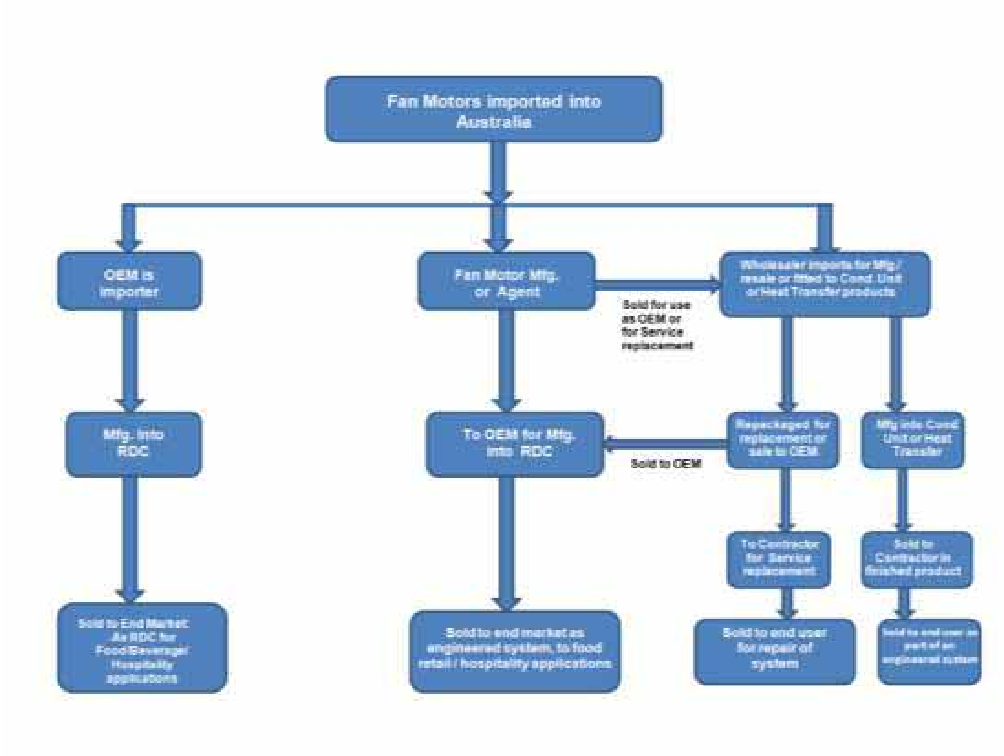
For EC motors (5 to 20W Sizes), some OEM's import their own motors and matched fan blades that optimise performance.

These importers often sell their products to local OEM's for applications like:

- Refrigerated Display cases;
- Evaporators , Condensers and Condensing Units;
- Wholesalers, where they are the importer or agent sell them to OEM's or as replacement fan motors to service contractors.

All end sales are to refrigeration contractors who sell them to end users as an engineered refrigeration system as shown in Figure 50.

Figure 50: Flow chart of imported fan motors through various channels to end markets



4.4 Energy consumption and greenhouse gas emissions

Fan motors consume an estimated 4,360 GWh of electricity per annum; this is 33% of total energy consumption in non-domestic refrigeration (ES, 2007). The following Table 23 provides a breakdown of their energy by motor type.

Table 23: Estimated electricity consumption by fan motors used in non-domestic refrigeration, Australia

Fan Motor Type	No Installed	GWh pa.	% of GWh
Shaded-pole single-phase	2,446,200	385	9%
External rotor single-phase	2,002,300	2,185	50%
External rotor three-phase	2,190,880	1,790	41%
Totals	**6,639,380**	**4,360**	**100%**

Source: Based on modelling from ES, 2007.

Switching to high efficiency fan motors over a 10 year period would save approximately 1,000 GWh per annum by the end of this period, representing a 17% reduction in energy consumption.

4.5 Opportunities for improving energy use

There is a wide range of energy reduction opportunities existing with fan assemblies; each one of which will incrementally and independently reduce energy consumption. The key opportunities are listed in Table 24 and below.

Table 24: Potential energy savings from switching motor types

Existing Motor Type	Capacity	New Motor	Existing Motor	New Motor	% Av. Energy
Shaded-pole: single-phase	5-70W	EC single-phase	20-30%	60-70%	58%
External rotor: single-phase	70-770W	EC single-phase	40-60%	90-95%	44%
External rotor: three-phase	500-2000	EC three-phase	75-85%	90-95%	15%

- Fitting voltage regulators on air-cooled condensers using 2 to 4 fans can save up to 50% energy and generally has a payback to the owner in less than 6 months;
- Fitting variable speed (VSD's) drives to air-cooled condensers using 5 fans or more can save up to 50% energy and generally has a payback to the owner in less than 12 months.

Many large users are slowly investing in more efficient fan assemblies, with clear trends emerging as follows:

- EC motors are now specified in new supermarket cases by the two largest supermarket chains (Coles and Woolworths) versus shaded-pole type;
- Fitting voltage regulators to small air-cooled condensers;
- Fitting VSD to larger air-cooled condensers;
- Fitting EC motors to large condensers on new installations with the payback improved by higher fan speed extracting more heat allowing the use of smaller condensers sizes.

4.6 Barriers to energy efficiency

Industry sources advise the major barriers to entry for new higher efficiency motors include:

- Capital investment: A payback of less than two years is required by many larger organisations when considering EC technology;
- Technology awareness: There are still misunderstandings and misapprehensions by the end-users and contractors regarding the current status of new fan motor technologies, and their costs and benefits. In particular;
- There is a failure to use EC motors in the large replacement market, even though EC motors have twice the life expectancy of small shaded-pole motors. In reality poor cleaning practices lead to failure of all motor types earlier than their technical lifetime;
- There is a lack of knowledge of the benefits of speed controllers for three-phase fan motors;
- Contractor cost: the majority of contracts are won of the basis of the lowest bid price, regardless of the reduced running costs available from higher investment levels;
- Market prices have yet to stabilise between old and new technology, for example;

- Local market prices for EC motors quoted can be 2.5 times higher than existing technology, while overseas prices indicate that the gap in more mature markets is considerably smaller;
- Inefficient system design reduces effectiveness of high performance fan motors and blades.

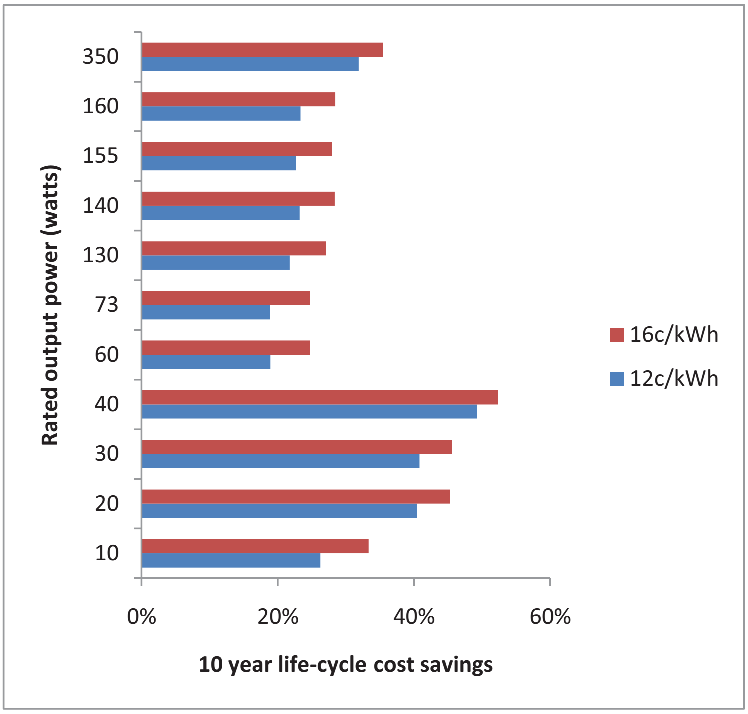
4.6.1 Cost benefit analysis

The financial implications of moving to more efficient motors are typically examined using life-cycle analysis comparing the total of capital and running costs for products which provide an equivalent level of service, while using differing levels of energy. This approach takes into account the higher replacement rate of shaded-pole and external rotor motors compared to EC motors.

In this analysis, the life-cycle costs of 22 motors comprising eleven sets of equivalent rated output power, from 10 to 350 Watts were compared. Using an industry average run-time of 16 hours/day, and a prices supplied by industry, the net benefit over ten years of purchasing the more energy efficient motors (in this case EC motors) are shown in Figure 51 and Figure 52. The results for an electricity cost of 12 cents/kWh and 16 cents/kWh are shown.

These results show that the financial benefits of switching to more efficient motors outweigh the costs in every example, and that the savings are considerable.

Figure 51: 10 year life-cycle percentage cost savings, 10% discount rate, 12c/kWh and 16c/kWh electricity costs



Source: MEA modelling estimates (see section 11 for further details)

Figure 52: 10 year life-cycle cost savings, 10% discount rate, 12c/kWh and 16c/kWh electricity costs

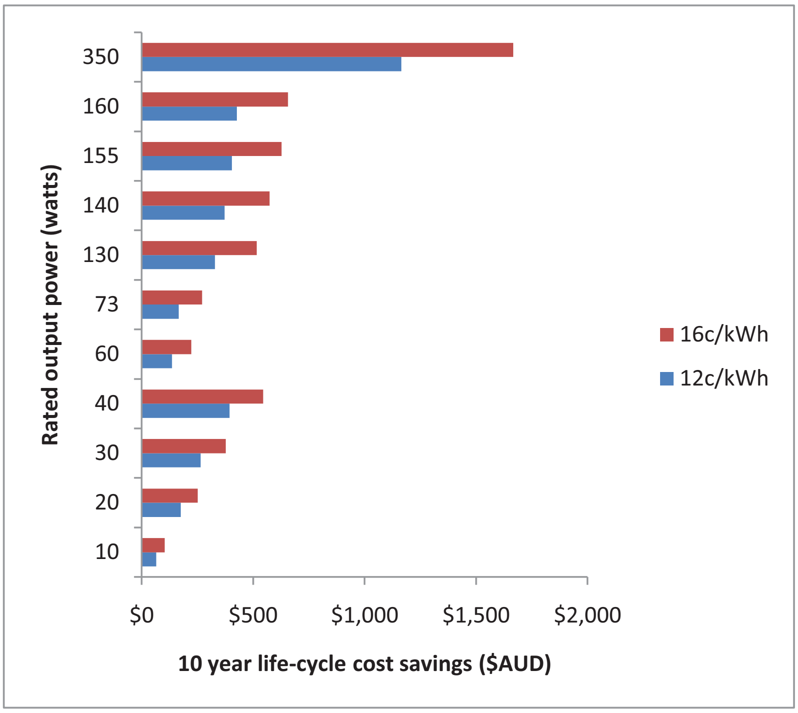
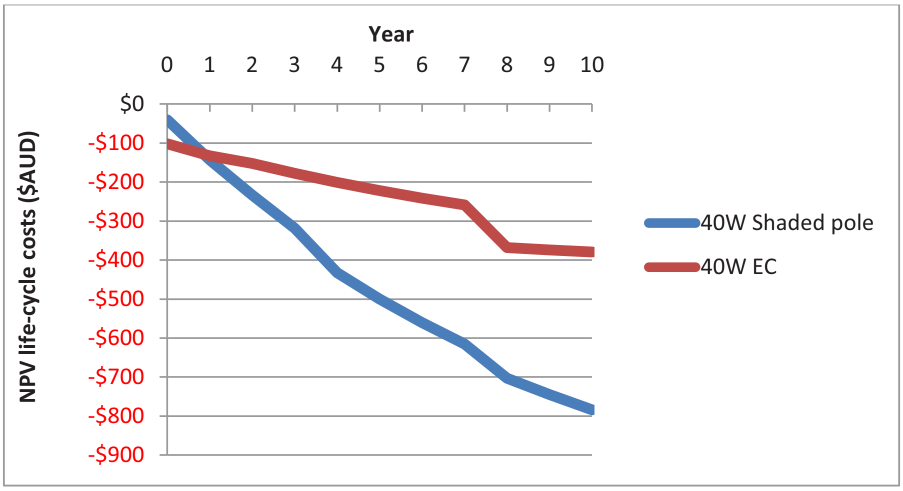


Figure 53 shows the discounted cash-flows for a 40 Watt shaded-pole and equivalent EC motor based on electricity costs of 12c/kWh, indicating a payback period of approximately one year.

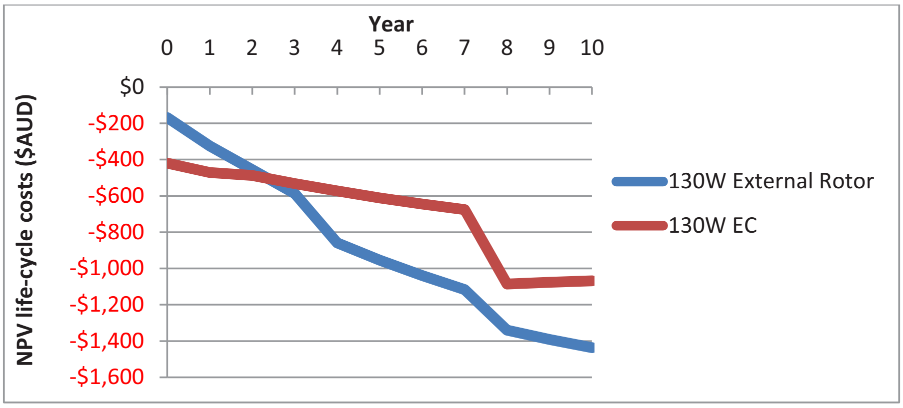
Figure 53: Life-cycle costs of 40W motor options, 10% discount rate, 12c/kWh electricity costs



Source: MEA modelling estimates (see section 11 for further details)

The cash-flow for a 130 Watts external rotor motor is compared to that for a 130 Watt EC motor in Figure 54. With electricity costs of 12c/kWh the payback period is three years, reducing by one year if electricity costs increase to 16c/kWh.

Figure 54: Life-cycle costs of 130W motor options, 10% discount rate, 12c/kWh electricity costs

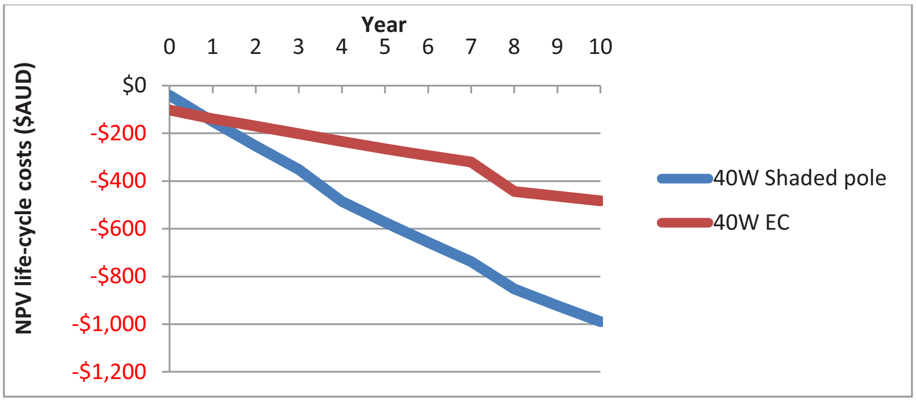


Source: MEA modelling estimates (see section 11 for further details)

The same cash-flows are shown in Figure 55 and Source: *MEA modelling estimates (see section 11 for further details)*

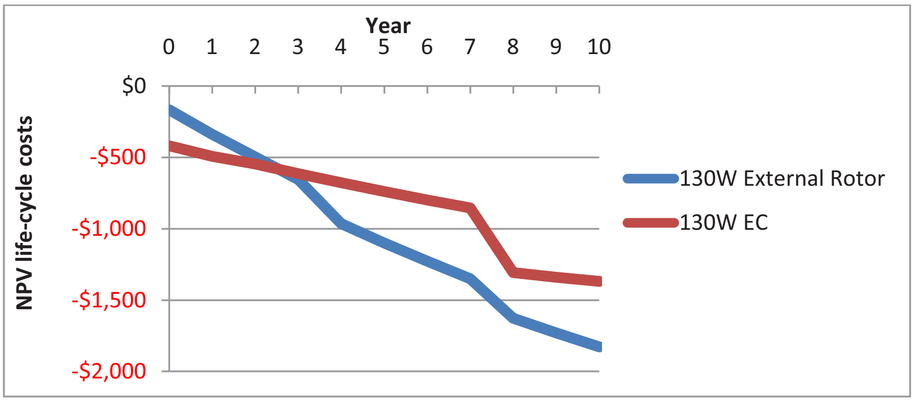
Figure 56 using an assumed discount rate of 5%, which further improves the cost-effectiveness of moving to more efficient motors.

Figure 55: Life-cycle costs of 40W motor options, 5% discount rate, 12c/kWh electricity costs



Source: MEA modelling estimates (see section 11 for further details)

Figure 56: Life-cycle costs of 130W motor options, 5% discount rate, 12c/kWh electricity costs



Source: MEA modelling estimates (see section 11 for further details)

4.7 Australian policies

Most fan motors used in non-domestic refrigeration are not covered by Australian or New Zealand Standards, or by any existing energy efficiency programs in either country.

MEPs for three-phase cage induction motors with ratings from 0.73 kW up to, but not including, 185 kW are specified in AS/NZS 1359.5:2004. The relationship of these energy performance requirements to fan motors used in non-domestic refrigeration applications is shown in Table 25.

Table 25: Scope of existing motor MEPs in relation to non-domestic refrigeration fan motors

Fan Motor Type	Covered by	Exclusion reason
Shaded-pole: single-phase	No	Standard does not cover single-phase motors
External rotor: single-phase	No	Standard does not cover single-phase motors
External rotor: three-phase	No	Standard does not cover integral assemblies Motor/Fan
EC: single and three-phase	No	Standard does not cover variable speed motors
TEFC: three-phase	Yes	Covers motors within kW range of standard

Selection of fan motors for appliances is covered by various safety standards that are not related to efficiency but which must be taken into account when replacing motors. This is even more important if a replacement motor is fitted to refrigeration equipment that uses flammable refrigerant.

Standards applicable to fan motors used as components in the following equipment:

- Vending Machines: AS/NZS 60335.2.75:2005 Household and similar electrical appliances – Safety – Part 2.75: Particular requirements for commercial dispensing appliances and vending machines;
- Air conditioning units: AS/NZS 60335.2.40:2006 Household and similar electrical appliances – Safety – Part 2.40: Particular requirements for electrical heat pumps, air-conditioners and dehumidifiers
- Commercial Refrigerating appliance including RDCs both remote and integral: AS/NZS 60335.2.89:2002 Household and similar electrical appliances – Safety – Part 2-89: Particular requirements for commercial refrigerating appliances with an incorporated or remote refrigerant condensing unit or compressor

4.8 International standards review

As in Australia, several economies now have minimum energy performance standards in place for three-phase, cage induction motor (Boteler et al., 2009). To assist the harmonization of performance standards, IEC 60034-30 (2008) defines the following three levels of energy efficiency, with the intention that countries will set national MEPS requirements at one of these thresholds:

- Premium Efficiency; IE3
- High Efficiency; IE2
- Standard Efficiency. IE1

However as noted above, these do not apply to the majority of fan motors used in non-domestic refrigeration applications. IEC 60034-3 defines energy efficiency classes for single-speed, three-phase, 50 Hz and 60Hz, cage induction motor (Boteler et al., 2009).

In the United States since 2009, fan motors for use in walk-in coolrooms (WICs) are required to be EC or PSC type, as mandated under the Energy Independence and Security Act of 2007 (EISA), section 312 covering walk-in coolers and walk-in freezers (DOE, 2007).

Also in the United States, the Department of Energy (DOE) has determined that energy conservation standards for small electric motors are technologically feasible and economically justified. As part of this process, the DOE passed a final rule on the test procedures to measure the energy efficiency of small electric motors on July 7, 2009, as follows:

- Single-phase small electric motors: either IEEE Std 114 or CAN/CSA C747;
- Polyphase small electric motors less than or equal to 1 horsepower (0.746 kW): IEEE Std 112 Test Method A; or
- Polyphase small electric motors greater than 1 horsepower (0.746 kW): IEEE Std 112 Test Method B (DOE 2009).

Consultation on the mandatory performance levels to be adopted under the Energy Policy and Conservation Act are underway.

A new test standard for converter-fed AC motors, IEC 60034-2-3, has been under development and issued as a working draft in 2008. This identified the test method for determining losses and efficiency, accounting variable torque and speed (Brunner, 2009).

Currently fan efficiency relates to the motor efficiency only and is expressed as a percentage for a nominated shaft power in watts, not including the fan blade. A new international test method for the fan motor and blade has been developed (ISO 5801), and an energy performance standard for fan motors and blades is under development by International Organisation for Standardisation (ISO) committee TC117 will also include motor & blade efficiency to be expressed in watts/litre/sec, to be published as ISO 12759 (Corry, 2009).

4.9 Recommendations

There is considerable potential to reduce energy consumption and life-cycle costs through increasing the uptake of more efficiency fan motors, with good prospects that policy measures which grow the market for these products will bring about further cost reductions.

It is therefore recommended that:

- Minimum energy performance standards (MEPS) are introduced for motors typically used in non-domestic refrigeration applications, with an output power rating of between 5 Watts and 2,000 Watts;
- MEPS should apply to fan motors offered for sale in Australia and New Zealand at the earliest opportunity that allows for reasonable adjustment by suppliers and customers. It is considered likely that this might be towards the end of 2012.
- The following MEPS levels are recommended for fan motors used for non-domestic refrigeration:
    - All single-phase fan motors with an output power rating of between 5 Watts and 70 Watts offered for sale shall have an energy efficiency of 60% or greater;
    - All single-phase or three-phase fan motors with an output power rating of between 71 Watts and 2,000 Watts offered for sale shall have an energy efficiency of 90% or greater. This requires further consideration in order to maintain consistency with other MEPS regulations;
- Further consideration should be given to the relationship with AS/NZS 1359, with the potential to incorporate these new requirements within future revisions of AS/NZS 1359;
- Further consideration should be given to the appropriate measurement method(s), including an comparative examination of IEC 60034-2-3 (draft) and the US test methods;
- Once the test method for fan assemblies has been completed, ISO 12759, consideration should also be given to the extension of MEPS to these products.

4.10 References

AS/NZS 1359 (2004)	Rotating electrical machines—General Requirements.
Brunner (2009).	pers. Com., 18 May 2009.
Corry, W.T.W. (2009)	ISO 12759 Energy Efficiency Classification for Fans: An explanation and Update, Chairman of ISO/TC117.
DOE (2007)	US Department of Energy, Energy Independence and Security Act of 2007, Energy Savings through improved standards for appliances, Section 312; Walk-in coolers and walk-in freezers, Washington DC, 4 January 2007.
DOE (2009)	Appliances and Commercial Equipment Standards, Building Technologies Program, see http://www1.eere.energy.gov/buildings/appliance_standards/commercial/small_electric_motors.html
ES (2007)	Cold Hard Facts, prepared by Energy Strategies in association with Expert Group, 2007
Boteler R., Brunner C., De Almeida A., Doppelbauer M. and W. Hoyt (2009)	Motor MEPS Guide, Information on the introduction of new testing standards, efficiency classes, labels and minimum energy performance standards MEPS for electric motors in global markets, Zurich, 2009.

5 Supermarket Refrigeration

Supermarkets are the largest single end-users of energy used in the commercial refrigeration sector, accounting for approximately 34% of total electricity used for commercial refrigeration in Australia. A supermarket is made up of a highly complex, interactive mix of equipment, technologies and services designed, installed and maintained by industry specialists. These specialists and owners of equipment generally understand industry best practice; however fail to deliver significant emission reduction opportunities.

This section seeks to provide a description of the key equipment types, provide a market profile with estimates of electricity consumption and Greenhouse gas emissions and discuss key energy reduction opportunities. These opportunities go beyond improved display case designs with doors or improved cold air containment and make recommendations to guide the industry towards best practice.

5.1 Description of technology

The main refrigeration equipment in supermarkets comprises central plant (rack systems) and remote condensing units servicing display cases and walk-in coolrooms (WICs), with additional self-contained merchandisers located throughout the store. This equipment includes a mix of mechanical components including compressors, evaporators, condensers, fans and associated controls engineered for specific refrigeration loads.

The types of equipment and refrigeration load varies based on the size of the store (m^2 of trading or sales floor), category of store and the amount and mix of fresh, chilled and frozen produce. Larger stores contain central rack systems located in a plant room or on the roof servicing the majority of the refrigeration load, while smaller stores generally have multiple individual systems (sometimes distributed to minimize refrigerant runs) to service the main loads.

5.1.1 Centralized refrigeration system

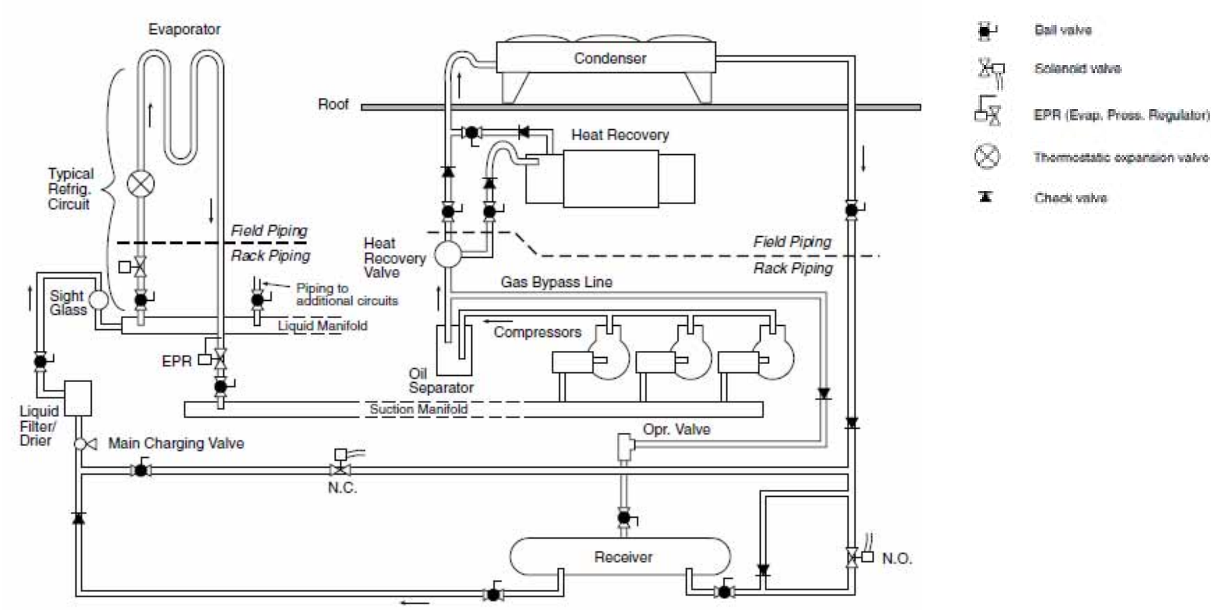
Most large to medium sized supermarkets use centralised refrigeration systems, as illustrated in Figure 57 below. This only shows one compressor rack while a typical mid to large store will have two medium temperature and one low temperature rack.

Figure 57 shows refrigerant leaving the compressor, passing through the oil separator before moving to the heat recovery coil which is located in the supermarket HVAC system. The heat recovery valve allows bypassing of this coil when heat is not needed. The refrigerant then is condensed, typically in a roof-mounted air-cooled condenser. Condensed refrigerant is collected in a receiver, which feeds the liquid manifold.

The dashed lines in Figure 57 show separation between the rack and store piping that services the evaporators contained in display cases and WICs. The balance of the system is made up of piping, insulation, valves and controls. This system does not have mechanical sub-cooling; which can be used for hot refrigerant gas defrost on low temperatures systems.

Each of the key components of a refrigeration system including display cases, WICs, rack systems and refrigerants are described in more detail in the following sections.

Figure 57: Schematic of a typical large supermarket system



5.1.2 Display cases

The most visible elements of the supermarket refrigeration system are display cases whose primary task is to hold and refrigerate produce for self-service shopping. Display case designs are driven by consumer merchandising to maximize retail sales (or gross margin return on investment of products and floor space) and food preservation more so than energy efficiency. This is why vertical open display cases that take up less trading floor per product turnover are very popular despite their high energy consumption when compared to horizontal display cases with sliding lids.

The most common types of display cases are seen in Figure 58 to Figure 62:

- Open multi-deck;
- Glass door upright freezers; and
- Deli/seafood display cases.

The refrigeration load required to service display cases is generally broken into medium temperature (-5 to 5°C) storage, accounting for up to 80% of the total energy consumption, with the balance comprising low temperature cases at -20°C to -25°C. Each display case contains an expansion valve, one or more evaporators and evaporator fans to circulate air. The display cases are connected to the central plant via high pressure liquid and suction refrigerant piping with additional connections required for condensate drain lines and electricity.

The refrigeration effect required to chill or freeze the produce can be lost through the insulation, display glass or with open display cases significant amounts of energy can be wasted by allowing refrigerated cold air to spill into the supermarket only to be heated up by the air conditioning system. The effect of the spillage can be minimised with air curtains where air is blown over the open section of the case, creating an air curtain, which separates food from the warmer store air or simply by placing doors on display cases.

The insulation and thermal properties of display cases varies significantly with new European design cases using polyurethane (EPU) with medium temperature cases typically 38 mm thick on the back and base (with 25 mm on front and top) and freezers slightly thicker with 43 mm on the base (with 38 mm in the back and top[15]). A significant portion of energy is lost through glass doors or when consumers' open doors to select produce. New vertical freezers are fitted with triple glazed glass filled with inert gas to improve the thermal resistance of the glass and anti-sweat glass heaters to prevent condensation forming to ensure consumers have a clear view of products.

Low temperatures and some medium temperature evaporators require periodic defrosting to remove frost, which condenses and/or freezes on the evaporator surface. This can be done with electric heating; refrigerant hot gas or air defrosts. Electric defrost uses electric resistive heating elements integrated into the evaporator coil. Hot gas defrosts involves piping and valves, which send hot refrigerant gas from the compressor discharge into the evaporator. Some medium temperature cases can also use off-cycle or air defrosts.

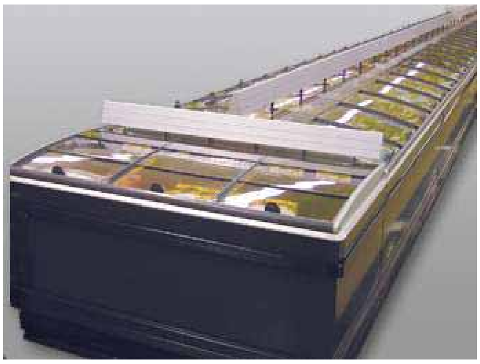
Figure 58: Refrigerated display cabinet open deck meat case

Figure 59: Refrigerated display cabinet vertical glass door freezer

[15] The thickness of insulation on self-contained glass door refrigerated display cabinets found in supermarkets and other food retail applications in Australia and New Zealand is typically 50 mm on medium temperature and 75 mm on low temperature.

Figure 60: Refrigerated display cabinet deli / seafood display case

Figure 61: High efficiency horizontal 'coffin' style freezer with lids



Source: Frigrite

Figure 62: Self-contained high efficiency horizontal 'coffin' style freezer operating on natural refrigerants

Source: Aldi 2008

5.1.3 Walk-in coolrooms (WIC)

Supermarkets use WICs for the temporary storage of delivered products. WICs include low temperature varieties, called walk-in freezers (freezer rooms), and medium temperature areas, called walk-in coolers (cold rooms). WICs may be incorporated with display cases, accessible by customers from the store interior.

WICs for all applications in the refrigerated cold chain are discussed in more detail in Section 6. WICs used in supermarket applications are generally 10 x 10 meters or larger, and have a higher thermal performance specification than others, constructed from 100 mm thick EPS (medium temperature) and 150 mm EPS (low temperature). The use of higher thermal rated insulation, such as PIR, is emerging within new stores, together with improved door sealing systems and greater consideration of energy efficiency designs and practices.

5.1.4 Compressor rack system

The heart of a centralized supermarket refrigeration system is the compressor rack system located either in a separate plant room or more recently on the roof, to save valuable real estate and installation time.

A typical supermarket will have 8 to 12 compressors ranging in capacity from 7.5 to 22.5 kWr serving both low and medium temperature demands. The medium temperature rack will have 6 to 8 parallel-connected compressors serving a series of loads with nearly identical evaporator temperatures.

Most compressor racks are 'uneven parallel', meaning the capacities of compressors in the rack are not equal. This improves the ability for the system to handle part-load conditions efficiently. Most racks use semi-hermetic compressors operating on HFC refrigerants, which are illustrated below in Figure 63.

Centralised supermarket refrigeration systems are highly complex and evolving rapidly, spanning a range of alternative technologies and processes. These include types of compressors (scroll and screw), refrigerants (CO_2 and ammonia) and different design configurations (cascade secondary loop, 'CO_2 only' and hybrid with different systems for low and medium/high temperature). All of these design options offer a range of energy saving opportunities and are explained in more detail in the following sections.

Figure 63: Typical parallel compressor rack

Figure 64: Parallel compressor rack system with a liquid receiver and suction accumulator

Source: Bitzer

5.1.4.1 Refrigerants

Refrigerants, the heat transfer fluids used in refrigeration systems, play a critical role in determining system operational performance and direct emissions resulting from refrigerant leaks. Supermarket systems have experienced several generations of refrigerants from the phase out of CFCs (R12 and R502) in 1995, to HCFCs refrigerant (R22), to HFCs (R404A/R507 and R134a), to alternative refrigerants (R744-CO_2 and R717-ammonia).

The large majority of supermarkets in Australia now operate on HFCs (R404A/R507 and to a lesser extent R134a). A recent study by Energy Strategies estimated the supermarket refrigerant bank to be 1,800 metric tonnes with more than 88% HFCs, less than 0.2% alternative refrigerants and the balance HCFCs (ES, 2008). Supermarket systems represent around 6% of the overall refrigerant bank in Australia and 18% of direct emissions due to refrigerant leaks (EG, 2009). The high leak rates of existing supermarket systems is the primary reason for considerable debate regarding which design configuration and refrigerant is best suited to which applications, with the main alternatives comprising:

- Cascade systems with HFCs (R404A or R134a and R744-CO_2);
- Cascade systems with natural refrigerants (R717-ammonia and R744-CO_2);
- CO_2 only systems (R744 only).

These alternative systems are discussed in more detail in the sections that follow. Other alternative refrigerants used in supermarkets includes propane (R290), used in self-contained freezers with very small refrigerant charges relative to centralized systems. A listing of the propane systems can be viewed on Queensland Government, Department of Mines and Energy, HC appliance register, which includes an Austral Refrigeration freezer cabinet commonly used in Aldi supermarkets in Australia (QGDME, 2009), which is illustrated in Figure 67.

5.1.4.2 Cascade systems with HFCs

A cascade system, sometimes described as a secondary loop system is made up of two thermally connected refrigeration circuits or 'loops', working together as a single system. One loop uses a primary refrigerant such as HFCs (R404A or R134a) and the other uses a secondary refrigerant. This configuration allows a smaller HFC refrigerant charge (approximately 30% of conventional system) acting as the primary refrigerant to be contained in the plant room, with CO_2 as the secondary refrigerant circulated to display cases on the trading floor. There are at least seven supermarkets operating cascade systems with HFCs in Australia servicing low and medium temperature application, with plans for more (EG, 2009).

A study by Solvay Fluor GmbH into alternative refrigeration systems found the energy savings of these systems were marginal (less than 5% versus conventional systems) and were up to 20% more expensive (Solvay Fluor GmbH, 2005). A study by the University of Bristol reported potential energy savings of 13 to 18% compared to an R404A reference system (UB, 2008). Accurate energy performance gains from these systems are still uncertain, although there are greater environmental benefits obtained from the reduction of direct emissions from refrigerant leaks.

5.1.4.3 Cascade systems with natural refrigerants

These cascade systems operate with two separate, thermally connected refrigeration systems but use R717-ammonia as a primary refrigerant instead of HFCs. There is currently one system installed in Australia in a Cole's supermarket in Ropes Crossing in NSW. These systems are currently more expensive (estimated at 40% more than conventional systems) and are reported to deliver energy efficiency gains of in the order of 10% (Solvay Fluor GmbH, 2005). These systems have virtually nil direct emissions from refrigerant leaks as the Global Warming Potential (GWP) of ammonia is zero and CO_2 is 1, which is close to zero.

5.1.4.4 CO_2 only systems

CO_2 was one of the earliest refrigerants, originally superseded by CFCs, but now experiencing resurgence. These systems are similar in operation to a conventional refrigeration system with one refrigeration loop, although the CO_2 refrigerant operates at higher pressures than in a conventional HFC direct expansion system, and are available for low and medium temperature applications. 'CO_2 only' systems are considered more commercially viable in low ambient temperature applications. Generally systems produce significant energy gains (up to 40% reduction) in the winter months, and increased energy consumption (up to 15% increase) in the summer months.

In Australia there were early 'CO_2 only' system trials during 2002 in Canterbury Gardens in Victoria and Mawson in South Australia (AIRAH, 2005). In 2008, Drakes supermarket installed the first trans-critical CO_2-only cooling system in Australia without any back-up system in its North Adelaide store, which was part funded by the Greenhouse Gas Abatement Program (GGAP). No official performance results have been released, however initial indications from industry sources suggest the overall annual energy reduction is in the order of 10%.

'CO_2 only' can be used in hybrid configurations where a conventional HFC refrigerant system can be used on medium temperature and 'CO_2 only' on low temperature. In summary, refrigerant choice is driven by potential reductions in both direct and indirect emissions per cost of kWr and there is no clear technology path with refrigerants in supermarket applications.

5.2 Market profile

The key stakeholders in supermarket refrigeration technology are major food retailers, supermarket contractors, capital equipment and key component suppliers, and refrigeration equipment wholesalers.

5.2.1 Food retailers

The major food retailers in Australia (Coles and Woolworths) have engineering, service (asset management) and sustainability teams that all have an interest in refrigeration technology, energy consumption and emission reduction. Coles have full service supermarkets operating more than 750 stores (including 65 BI-LO stores) throughout Australia, accounting for 23% of food retail spend and employ more than 92,000 people. Woolworths is one of Australia's largest and most diversified retail companies, which operates more than 3,000 food retail stores in Australia and New Zealand, accounting for 31% of food retail spend and including more than 760 major supermarkets in Australia (Woolworths, 2008b).

IGA distribution (division of Metcash) supplies over 2,700 independent grocery stores and provides marketing, merchandising, buying, technical, operational and distribution support services to over 1,200 IGA stores and product distribution for more than 570 Foodworks stores. IGA/Metcash accounts for 17% of food retail spend. Aldi operate over 200 stores across the eastern seaboard of Australia. Aldi stores are not full service supermarkets and have less refrigeration requirements than major supermarkets.

The size (m^2 of trading or sales floor) and type of supermarket (amount and combination of fresh, chilled and frozen produce) influence the amount of refrigeration required, the type of refrigeration plant and equipment. The number of supermarkets, nominal size and type of refrigeration equipment is outlined in Table 26 below.

85% of the total electricity consumed by all supermarkets is estimated to be from central systems, while individual multi systems with remote condensing contribute 11%. Self-contained units account for 4% of supermarket electricity consumption.

Table 26: Number of supermarkets, size and type of refrigeration equipment

Size	Nominal trading floor size (m^2)	# Stores 2009	Type of refrigeration equipment
Large	3,800	1,210	Centralized plant & self contained units
Medium	2,500	1,540	Centralized plant, some individual multi systems & self contained units
Small	650	1,035	Individual multi systems & self contained units
Total		3,785	

5.2.2 Supermarket contractors

Supermarket refrigeration systems and equipment are mostly installed and serviced by large contracting businesses that specialise in this sector. The supermarket contractors are made up of national companies with engineering and service teams including:

- Mc Alpine Hussmann, a subsidiary of Ingersoll Rand;
- Frigrite, an Australian owned company;
- Austral Refrigeration, a division of the Hastie Group, and;
- Regional players such as John A Gordon, Contract Refrigeration, A.J. Baker and Alkar.

City Refrigeration Holdings (UK) Ltd, one of Europe's largest privately owned facilities management companies, is establishing a substantial presence in Australia in partnership with Coles, and has set up a subsidiary company, City Facilities Management (Aust) Pty Ltd.

5.2.3 Equipment and component suppliers

The key capital equipment and component suppliers to the supermarket sector are:

- Rack systems and compressors: Bitzer and Copeland a division of Emerson;

- Heat transfer equipment: Buffalo Trident a subsidiary of Bitzer, Kirby a brand of Heatcraft, Guntner, Greenhaugh and Lu-ve Contardo;
- Fan technology: EBM Papst and Ziehl Abegg;
- Total Energy Management Controls used for the control of refrigeration systems, lighting, air conditioning and other energy saving activities such as automation of night blinds are supplied by Emerson (CPC Products and Alco Electronics), Carel, Phasefale and Danfoss;
- Wholesalers of refrigeration components and accessories including pipe, insulation, and refrigerant include Heatcraft, Actrol, Airefrig and Patton Refrigeration;
- Display cases are largely supplied by national supermarket contractors and self-contained equipment by a wide range of cabinet suppliers including Skope Refrigeration, Orford Refrigeration, Chill Flow and food retailers.

5.3 Energy consumption and greenhouse gas emissions profile

The supermarket segment is the largest user of energy in commercial refrigeration consuming an estimated 4,600 GWh (34% of total), the best part of 4% of all electricity consumed in Australia. The emissions profile from commercial refrigeration is more significant with estimated indirect emissions of 4,650 kt CO_2-e plus 20% or more in direct emissions due to refrigerant leaks. Woolworths reported direct emission of 610 kt CO_2-e and indirect emissions of 2.6 Mt CO_2-e where as Coles reported total emissions of 2.9 Mt CO_2-e of which 900 kt CO_2-e was direct emissions calculated based on NGERS default refrigerant leak rates for air conditioning and refrigeration equipment (Woolworths, 2008a and Westfarmers, 2008). Table 27 provides a breakdown of the energy use by supermarket size.

Table 27: Electricity consumption by store size

Store size	No stores	Refrig. capacity (kWr)	Electricity consumption (GWh p.a.)	% of Supermarkets energy use
Large	1,210	350,000	2,323	50.5%
Medium	1,540	230,000	1,932	42%
Small	1,035	60,000	345	7.5%
Total	3,785	-	4,600	100%

5.3.1 Trends in the supermarkets sector

The growth of the refrigeration equipment in the supermarket sector is projected to continue at 4% to 5% per annum with Woolworths predicting 40% growth between 2006 and 2015. Changing consumer preferences mean new stores tend to be larger and require more refrigeration to meet consumer preference for convenience meals that require refrigeration. Woolworths estimate that refrigeration accounts for 48% of the Greenhouse gas emissions from energy use in facilities. The average annual energy use per square meter in existing Woolworth stores in 2006 was 920 KWh/m^2, while new stores with increased refrigeration have a higher energy demand of approximately 1,200 KWh/m^2 (Woolworths, 2007).

Other trends and key drivers impacting on sustainable supermarket behaviour is ‘green consumerism’, government regulation (NGERS reporting and the pending introduction of CPRS), future energy prices and technical drivers such as Total Environmental Warming Impact (TEWI) calculations that take indirect and direct emissions into account (EG, 2009). These factors are influencing investment decisions in more sustainable technology. NGERS reporting is improving the understanding of direct and indirect emissions and how carbon prices could impact on running costs and refrigerant prices under a CPRS. TEWI if done correctly allows more informed decision making on investments in refrigeration systems and 'green consumerism' is encouraging supermarkets to be seen as more 'environmentally friendly' by adopting more sustainable practices. This behaviour is characterized by Woolworths 'Doing the Right Thing' campaign and the promotion of its 'green stores'.

5.4 Opportunities for reducing energy consumption and greenhouse gas emissions

A review by the University of Bristol, Food Refrigeration and Process Engineering Research Centre surveyed all published information available in developed economies on methods of saving refrigeration energy in supermarkets and other food retailing. A summary of technology options with potential to deliver savings in refrigeration power of 10% or more is listed in Table 28. Another study worth noting that provides similar testimony of savings is a study undertaken on the Trends and Perspectives in Supermarket Refrigeration by the Karlsruhe University of Applied Sciences in Germany (KUAS, 2006).

Table 28: Potential supermarket energy efficiency options

Priority	Technology	Saving in refrigeration energy	Application
1	Adding doors to display cases	Up to 50%	Chilled and frozen multi-decks
2	Strip curtains	30%	Chilled multi-decks
3	Optimisation of air curtain	30%	Chilled multi-decks, chest freezers
4	Night blinds	20%	Chilled multi-decks, chest freezers
5	Night covers	20%	Chilled multi-decks, chest freezers
6	Dehumidification	5 to 29%	All open cabinets
7	Trigeneration	20%	Supermarket system
8	Liquid pressure amplification	Up to 20%	All remote refrigeration systems
9	ECM/Variable speed compressor	15%	All integral and remote systems
10	High-efficiency compressors	12%	All integral and remote systems
11	Defrost optimisation	10%	Freezers (chillers should be operated on off-cycle)
12	Radiant heat reflectors	10%	Chest freezers and delicatessen cabinets
13	Multi-evaporator systems	10%	Freezers (indirect through removal of defrost heat load)
14	LED lighting	5 to 10%	All cabinets with lights

The key energy reduction opportunities in Australian supermarkets are as follows:

- Doors on display cases and/or improved containment of refrigerated cold air;
- Improved humidity control;
- Sustainable store designs;
- Improved maintenance practices, and
- Benchmarks to improve the efficiency of the existing stock of equipment in supermarkets.

Each of these opportunities is discussed in more detail in the sections that follow.

5.4.1 Doors on display cases

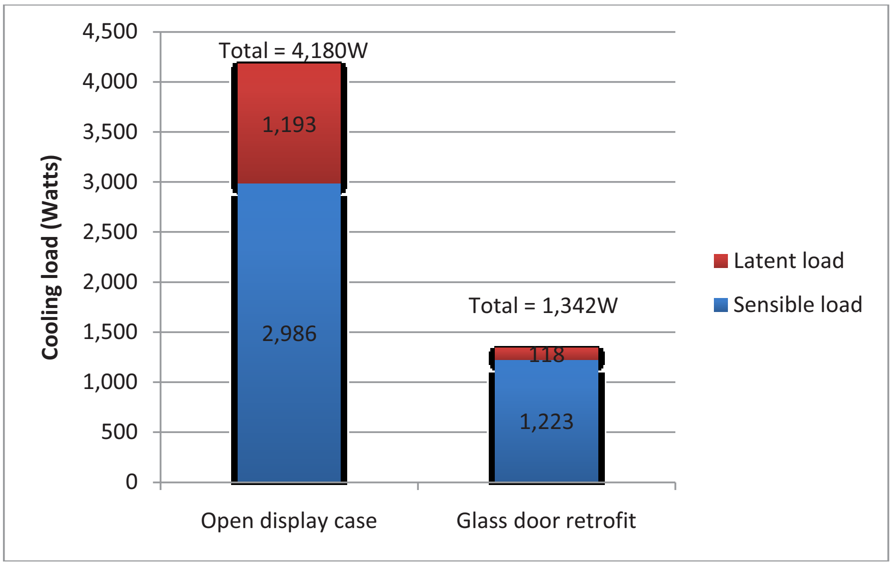
The top five opportunities listed in Table 28 relate to placing doors on display cases or improved containment of refrigerated cold air. Placing doors on display cases can deliver up to 50% in savings with reports of more in certain applications. Southern Californian Edison, Refrigeration and Thermal Test Centre (SCE RTTC) conducted a series of studies on supermarket equipment including evaluating the performance of an open style medium temperature five-deck dairy case to establish baseline test results then retrofitted the display case with glass doors and found adding glass doors reduced the cooling load by 68% (SCE RTTC, 2003a). The results are graphically illustrated in Figure 65 below.

Despite the significant energy savings from placing doors on refrigerated display cases there has been little interest in Australia with reports of some food retailers undertaking trials and no companies offering door retrofit kits in commercial quantities. Schott Termofrost offer a frame-door system in Europe and North America that they claim can be retrofitted to almost any medium temperature meat or dairy refrigerated display case and deliver energy savings of 30% based on results verified by the SP Technical Research Institute of Sweden (Schott Termofrost, 2009a). Schott have not offered these products in Australia; however have recently supplied other door retrofit kits to replace heated refrigerated display case doors with non heated versions that have a special coating that minimizes frosting (Schott Termofrost, 2009b) and retrofit doors lighting kits with LED lighting that can reduce energy consumption from lighting by up to 82% (plus remove the amount of heat that is added to the cold environment) with payback periods less than 2 years when replacing T8 or more with T10 or T12 (Schott Gemtron, 2009).

In most instances placing doors on display cases will provide the greatest energy savings, however it is not the only option. There is a range of techniques available to improve cold air containment including strip curtains, adding night blinds or covers (automatic or manual) when cases are not in use and case designs with air curtains that minimize air spill. Another study by SCE RTTC analysed the air curtain performance on a medium-temperature open vertical refrigerated display case and concluded air curtains could reduce warm air infiltration by 80% (SCE RTTC, 2002). The use of efficient air curtains is particularly suited to high usage medium temperature display case applications where the energy lost from a small amount of air spillage out-ways the energy lost from customers constantly opening doors.

This range of cold air containment solutions are not only suited to new display cases, in most instances they can be retrofitting to existing cases. Display cases with doors or designs that don't spill refrigerated cold air into the supermarket can save up to 50% of refrigeration energy consumption and is largely overlooked by food retailers due to merchandising concerns. Given the diversity of existing stock of display cases and range of options, a 20% improvement in the performance is plausible which could deliver a reduction of 920 GWh per annum. In August 2008, Sainsbury's opened the doors to the Dartmouth store in Devon in the UK, which at the time they claimed to be the 'greenest' store in the UK. This store was the first store in the UK to trial doors on medium temperature (chiller) cabinets in a high profile store.

Figure 65: SCE TTC, Reduction in cooling load, open display case versus glass door retrofit



5.4.2 Improved humidity control

Changes to indoor temperature and humidity have also been shown to improve energy efficiency, consumer comfort and food safety.

The Bristol University research found dehumidification had potential to deliver up to 29% in savings (UB, 2007). A study by the SCE RTTC into relative humidity (RH) found a 1°C increase in indoor temperature increased refrigeration power by 1%, and a 10°C increase in indoor wet bulb temperature (which reflects an increase in humidity) resulted in a 25% increase in the compressor power use (SCE RTTC, 2003c).

Further studies by SCE RTTC tested the performance of a variety of display cases when varying the RH from 35% to 55% (SCE RTTC, 2003b). They found there was a direct correlation between lowering RH and the mass of frost formed on the evaporator; defrost time, door fog refresh rate (69% reduction) and compressor run time (up to 20% reduction). They concluded supermarket designers and operators should consider cost-effective ways to maintain reasonably low RH in their stores, while complying with occupant comfort conditions. In doing so, they should evaluate the trade-off between refrigeration savings and air conditioning penalty. Furthermore, they can save additional energy under low indoor humidity conditions by using smart defrost and anti- sweat heater controls and in some instances can reduce air conditioning energy consumption.

The energy reduction opportunities with improved humidity control are widely published, with similar opportunities documented by ASHRAE in a data base review and case study of humidity effects on energy performance of supermarket refrigerated cases (ASHRAE, 2005). The findings on medium temperature refrigerated display cases are illustrated in Figure 66 and a summary of the findings from the studies discussed in this section is provided in Table 29.

Figure 66: Medium-temperature refrigerated display case load and compressor energy versus relative humidity at 24°C, (ASHRAE, 2005)

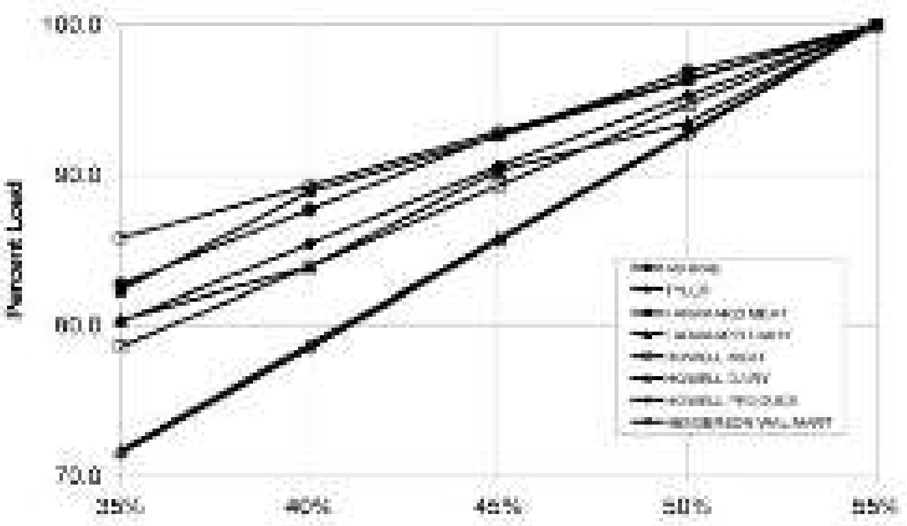


Table 29: Summary of energy saving opportunities from improved humidity control

Study	Type of study	Energy Saving opportunities
UB, 2007	Database review	Ranged from 5% to 29%
ASHRAE, 2005	Database review	Medium temp ranged from 14% to 28%
		Low temp ranged from 5% to 18%
SCE RTTC, 2003	Laboratory tests of low and medium temp cases	20% to 25% variation of cooling load on medium temp open display cases with less impact on low temp cases with doors

In Australia, the major food retailers have established minimum RH design guidelines (less than 45% to 55% depending on the food retailer). In practice air conditioning designs are often compromised due to split incentives between building developers (owners) and tenants (food retailers) with inadequate humidity control, insufficient use of RH sensors and limited use of remote diagnostic technology to collect data and optimize RH levels. Suppliers that specialize in humidity control such as Munters have modelled this opportunity and suggest a 10% improvement in refrigeration energy consumption is plausible. They claim the additional cost of an a system with improved humidity control in new stores is around $50,000 with a payback of less than 3 years and retrofitting existing store can be more difficult to justify with the additional cost of more than $100,000. A 10% improvement in refrigeration energy equates to a reduction of 460 GWh per annum.

5.4.3 Sustainable store design

New sustainable store designs such as Coles ‘environmental concept stores’ or Woolworths ‘green supermarket’ provide a practical demonstration of what is feasible. For example, Woolworths have announced that their first green store in Rouse Hill achieved a 36% reduction in CO_2-e emissions per m^2 compared to the business as usual store design (Woolworths, 2008a).

The mix of initiatives in the sustainable store designs varies depending on the size of store, geographical location, new or refurbishment and food retailer. The energy saving initiatives includes a combination of the following:

- Alternative refrigeration systems;
- Heat reclaim system (utilizes waste heat from the refrigeration system to heat, de-humidify and air-condition store);
- Heat recovery from refrigeration plant to heat water;
- Refrigeration system efficiency gains (in order of 5%) using evaporative wetted pads;
- High efficiency refrigeration cases based on state of the art European design;
- High efficiency fans;
- LED lighting in glass door freezers;
- Low heat glass freezer doors;
- Freezer aisle motion sensors to turn lights off when there are no shoppers around;
- Automatic night blinds to reduce energy consumption when the store is closed;
- Cold aisle return air on air conditioning systems;
- Economy cycle on air conditioning systems (uses fresh outside air);
- Fuel switching and additional insulation;
- Use of natural gas for bakery and chicken cookers in lieu of electricity;
- Energy management system to control, lighting, refrigeration and automatic blinds;
- Improved thermal energy rating on build shell;
- T5 lighting on trading floor;
- Natural lighting where practical;
- LED lighting for external signage;
- Most of non-trading area lighting controlled by passive infrared (PIR) sensors.

While extremely significant, it should be noted that growth in refrigeration demand in supermarkets is likely to erode a large proportion of these savings. This point is illustrated by the fact that the carbon target adopted by Woolworths foresees no reductions in 2015 emissions compared to 2006 levels.

In addition, it is noteworthy that the initiatives identified above do not include the single largest energy reduction opportunity, which is to eliminate open display merchandising.

The sustainable store design concept mostly applies to new stores rather than refurbishments. Stores are rarely closed when refurbished which makes structural changes to the building shell or the installation of an alternative refrigerant refrigeration systems prohibitive. With an estimated rate of less than fifty new stores per annum, it will take decades to populate the existing stock with sustainable design stores.

5.4.4 Improved maintenance practices

Improved maintenance practices including preventing and repairing leaks to maintain the ideal amount of refrigerant that optimises system performance, commonly referred to as ‘critical charge’ and cleaning dirty coils and replacing filters all play a vital role in equipment efficiency. Lack of maintenance can potentially cause a drop in operational efficiency of up to 30% or more in total. However, there are a number of barriers which prevent these opportunities from being realised.

The inherent difficulty in measuring the financial benefit of improved refrigeration maintenance practices remains one of the largest obstacles to reducing emissions from existing stock. Without proper benchmarks, measures and proven practices, financial department are often reticent to pay to fix something that appears to be working.

In addition, split incentives between building owners, tenants and corporate departments significantly impact on maintenance budgets and the operational performance of refrigeration systems.

Improved maintenance practices alone could easily achieve a 10% improvement in operational efficiency equivalent to 430 GWh per annum and half their direct emissions.

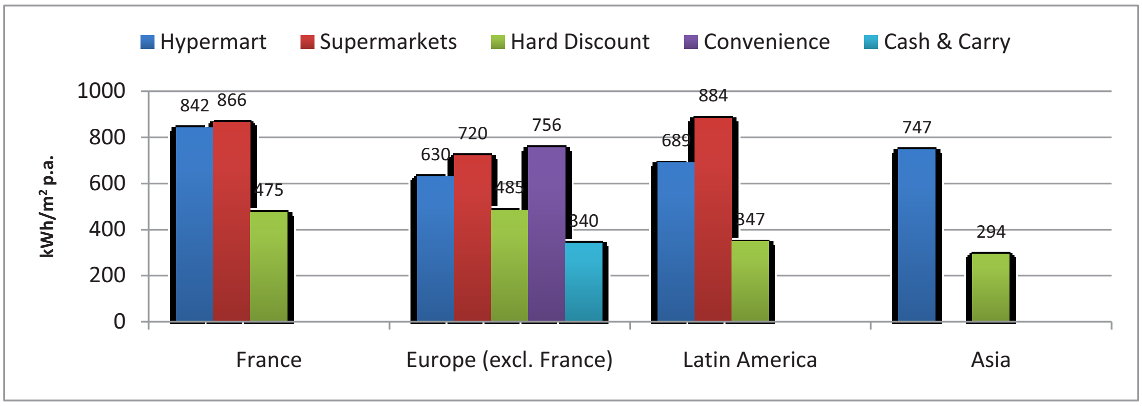
5.4.5 Supermarket benchmarks

Establishing benchmarks for total electricity consumption and/or emissions for supermarkets makes more sense than focusing on refrigeration energy consumption since supermarkets are made up of a highly complex, interactive mix of equipment, technologies and services that can affect each other's operational performance.

The interrelationship between refrigeration and air conditioning systems is a key example, with dehumidification having the potential to deliver energy savings on the refrigeration system of up to 29%. Additionally, air conditioning systems can utilise waste heat from the refrigeration system or have return air registers located over frozen food aisles.

In principle, benchmarks can be used to compare the performance of equivalent stores against each other. The energy consumption in supermarkets is normally specified in kWh/m^2 per annum of the sales area (or total store area which gives the impression of better performance) and can be defined as the energy intensity of the supermarket. For benchmarks to be effective, they must compare 'like for like' and take factors into account such as the type of store, climatic conditions, store sizes, amount of refrigerated produce and air conditioning (stand-alone or part of shopping centre). Carrefour, a leading European food retailer and multi-national business operating in 30 countries summarizes the average energy intensities by store type in Figure 67. This example illustrates the significant differences in energy intensity by store type or region and the importance of comparing 'like for like'. Supermarkets and 'Convenience Stores' have the highest proportion of refrigerated produce, which result in higher energy intensities than 'Hard Discount' and 'Cash & Carry' stores with more general merchandise. Hypermart stores have larger trading areas greater than 5,000 m^2 and a higher portion of general merchandise than supermarkets, which results in a slightly lower energy intensity. The performances of similar store types differ significantly from region to region, which can be explained by different store formats, product mixes, climates and equipment standards.

Figure 67: Carrefour energy consumption in kW/m^2 of sales area by store type and region (Carrefour, 2005)



Ahold, an international group with supermarkets based in the United States and Europe has been measuring and publishing energy intensity benchmarks since 2002. They claim tracking and benchmarking energy consumption assists them to identify stores with unusually high energy consumption, which allows them to take corrective action. In 2004 they introduced an intranet based system in Norway to remotely monitor and analyse the energy consumption of 275 stores from their head office, which resulted in a 10% reduction in energy consumption in the stores that were equipped with the system (Ahold, 2004). The benchmarks published by Ahold from 2002 to 2007 can be found in Attachment 3 along with a graphical illustration that shows a downward trend in energy consumption of their average store by more than 20% since 2003.

There are several independent benchmarking guides that provide energy efficiency performance data for commercial building, including supermarkets. In the UK, the Chartered Institution of Building Services Engineers publishes a guide that includes a benchmark for supermarkets of 600 kW/m^2 per annum (CIBSE, 2004). In the US, the Energy Information Administration conducts a national survey of commercial building energy consumption (CBECS, 2003) every 5 years that includes a measure of food stores of 49.4 kWh/ft^2 equivalent to 532 kWh/m^2 per annum (EIA, 2003). Both the CIBSE and CBECS measures are based on total store area. This range of benchmarks is consistent with the performance of Ahold supermarkets based on total store area listed in Attachment 3 that range from 503 kWh/m^2 to 607 kWh/m^2 per annum.

Woolworths estimated the average energy intensity of their supermarkets in 2006 to be 920 KWh/m^2 based on store area and new stores with increased refrigeration of 1,200 KWh/m^2 (Woolworths, 2007). This estimate is very similar to Sainsbury's average across a similar sample of over 750 supermarkets in the UK, which was calculated to be 913 kWh/m^2 per annum in 2005/6. Sainsbury's are likely to have some hypermarket stores that are larger than Australian stores; however the similarity suggests that benchmarks from supermarkets in the UK could be used to reflect performance of Australian supermarkets. Further details on energy performance of Sainsbury's stores can be found in Attachment 3, which shows that energy intensity has declined by over 9% against their 2005/06 baseline even with significant growth.

A recent independent study undertaken by the University of Bristol into supermarket and food retailing involved surveying close to 50% of stores of the main supermarket chains in the UK (BU, 2008). The study specified energy intensity in kWh/m^2 per annum based on sales area and the results are summarized in Attachment 3 (see Table 33 and scatter diagrams, Figure 72 and Figure 73). This data has been interpreted and summarized in Table 30 based on similar size categorizes to those in Australia, which are small (650 m^2), medium (2,500 m^2) and large (3,800 m^2).

Table 30: Energy intensity (kWh/m^2 p.a. for sales area) of supermarkets in the UK with similar sizes to Australian supermarkets (UB, 2008)

Category	Size of trading floor size (m^2)	Energy intensity (kWh/m^2 p.a.)
Large	≥ 2,750	930
Medium	≥1,500 and < 2,750	950
Small	< 1,500	1,100

It is widely acknowledged in Six Sigma practices and business management strategy that 'what is measured improves' and as demonstrated by Ahold and other supermarket chains introducing benchmarks will improve the performance of stores. There is a wide range of international data available on supermarket performance that provides insight into the current performance levels of Australian supermarkets. Industry sources suggest that whilst there is some performance measurement undertaken in Australia, there is significant room for improvement by all food retailers. Measures that introduce an effective benchmarking process to compare 'like for like' energy intensity of stores will assist in optimizing efficiency initiatives and provide an overview of the progress of the diverse range of energy reduction initiatives possible in supermarkets. The first step is to establish and agree on effective benchmarks that apply to the existing stock of supermarkets. If the electrical energy intensity of the average stores is reduced by an achievable 10% this represents an electrical energy saving in the order of 460 GWh per annum.

5.5 Australian standards

There are no current test or performance standards dedicated to centralized supermarket systems. The main standards and efficiency guides used in the supermarket industry cover equipment, components and accessories, they are as follows:

- AS/NZS 1677-1998 Refrigerating systems, Part 1 and 2, which is a mandatory standard that classifies and specifies safety requirements for all refrigerants, in terms of the design, construction, installation and inspection of refrigerating appliances, systems and ancillary equipment. This standard is considered the governing reference standard for designing supermarket refrigeration systems;
- AS 1731-2003 Refrigerated display cabinets, Parts 1 to 14, which includes energy performance test methods and MEPS requirements for both remote and self-contained refrigerated display cabinets commonly used in supermarkets. This standard is currently under review and is discussed in detail in Volume 1 of this review;
- The Australia and New Zealand Refrigerant Handling Code of Practice 2007; Part 1 Self-contained low charge systems and Part 2 Systems other than self-contained low charge systems, which was developed with the intention of reducing emissions into the atmosphere of fluorocarbon refrigerants during installation, commissioning and maintenance (replaces SAA HB 40, 1997);
- The Good Environmental Choice Australia: Supermarket refrigeration systems, which was issued in 2008 as a good practice guide for supermarket equipment although it is not currently widely used.

There is a range of standards used to specify performance, design, construction and installation requirements for components including compressors, heat transfer equipment, pressure vessels, piping, insulation and electrical requirements. For example, compressor suppliers typically nominate COPs based on the Association of European Refrigeration Compressors and Controls Manufacturers (ASERCOM) certified performances standards.

There is no industry consensus on rating of heat transfer equipment: some suppliers specify equipment based on dry atmosphere (sensible heat) according to Eurovent certified performance guidelines such as EN 328: 1999 *test procedures for establishing performance of unit air coolers for refrigeration.* Other suppliers state capacities based on ASHRAE Standard 25, 1990. At present all claims are unverified as there are no NATA accredited test facilities able to perform these tests in Australia.

All major Food Retailers have their own refrigeration system specifications that set out performance standards for new and refurbished stores. These specifications list *AS/NZS 1677-1998* as the governing standard that must be adhered to without exception and often only make generic statements about energy performance and efficiency.

Other relevant standards activities in the commercial refrigeration industry include growing interest in EN 378: 2008, Refrigerating Systems and Heat Pumps - Safety and environmental requirements, as the governing industry standard for refrigerating equipment and refrigerants. The ME006 Standards Committee is considering the possibility of adopting ISO 5149: 2009 Refrigerating systems and heat pumps - Safety and environmental requirements to replace AS/NZS 1677-1998 Refrigerating systems. Where ISO 5149: 2009 is essentially a mirror image of EN 378-2008 with references to EU directives removed and other changes to make it more suitable as an International Standard.

The timing of this review complements other industry activities such as a drive to develop a Total Environmental Warming Impact (TEWI) rating methodology standard for refrigeration system that takes into account both direct and indirect greenhouse emissions. Although TEWI is referred to quite widely in Europe, it is not well known or consistently applied in Australia and New Zealand. An industry-government TEWI working group plans to review current information on this subject and advise the ME006 on the suitability of the TEWI methodology used in ISO 5149: 2009.

5.6 Overseas policies and standards

The supermarket sector has the largest emissions profile of all commercial refrigeration sectors. International energy efficiency agencies, regulators and key stakeholders are constantly researching opportunities to reduce electricity consumption and contain direct emissions from fluorocarbon refrigerant leaks from supermarket systems. There are no current international tests or performance standards dedicated to centralized supermarket systems. There is a diverse range of International standards and regulations used to specify performance, design, construction and installation requirements for equipment, components and accessories used in supermarket systems including refrigerated display cases, compressors, heat transfer equipment, pressure vessels, piping, insulation and electrical requirements.

In North America the U.S. Department of Energy (DOE) has amended the Energy Policy and Conservation Act, section 136(c)(1) of the Energy Policy Act of 2005, to establish energy conservation standards for commercial refrigeration equipment manufactured on or after January 1, 2012. This includes commercial ice-cream freezers; self-contained commercial refrigerators, commercial freezers, and commercial refrigerator-freezers without doors; and remote condensing commercial refrigerators, commercial freezers, and commercial refrigerator-freezers. There has been considerable debate regarding closed and open refrigerated display cases in North America and there is a view that the efficiency standards for both types of equipment should be the same. Peak industry bodies such as ARI claimed that the minimum energy efficiency standards proposed by the Californian Energy Commission (CEC) under Title 20 in 2004 were in fact attempting to ban the sale of commercial refrigerators and freezers without doors in California. At present the CEC is collecting performance data to facilitate future consideration of open case performance standards.

DOE has adopted *ANSI/ARI Standard 1200–2006, Performance rating of commercial refrigerated display merchandisers and storage cabinets.* This standard sets out test, rating and conformance requirements and prescribes the use of *ANSI/ASHRAE Standard 72-2005, Method of testing commercial refrigerators and freezers*. DOE believes these standards to be a sound method to produce results that accurately reflect the efficiency of both open and closed refrigerated display cases. Another notable standard is Canadian standard *CSA C657-04 Energy performance standard for commercial refrigerated display cabinets and merchandisers.* A general standard in common use is *ANSI/ASHRAE 15-2001, Safety Standard for refrigeration systems*, which sets out design, construction, test, installation, operation, and inspection of refrigeration systems.

Current policies in Europe and the UK are focusing on improving the energy efficiency of components such as compressors and fan motors. The most notable are ASERCOM certified performances standards for compressors and Eurovent certified performance guidelines such as *EN 328: 1999 Test procedures for establishing performance of unit air coolers for refrigeration* for heat transfer equipment. Other relevant standards include, *BS EN 13771-2:2007, Compressors and condensing units for refrigeration, which covers p*erformance testing and test methods for compressors and condensing units. *ISO TC 86/SC 1 to 8* has a comprehensive scope encompassing safety and environmental, testing and rating of compressors, refrigeration systems and refrigerated display cabinets and refrigerants for refrigeration and air conditioning.

Supermarket refrigeration technology is evolving rapidly due to the use of alternative refrigerants such as CO_2, Ammonia and hydrocarbons (in self contained systems) in a quest to improve efficiencies and reduce emissions from fluorocarbon refrigerant leaks. The main international standard used as a reference for designing, installing and maintaining supermarket refrigeration systems is *EN 378:2008, Refrigerating Systems and Heat Pumps - Safety and Environmental Requirements*, with Parts 1 to 4 covering various safety aspects associated with the use of all refrigerants covering basic requirements, design, installation, maintenance, repair and refrigerant recovery. *EN 378:2008* addresses the use of natural refrigerants such as CO_2, Ammonia and hydrocarbons that are emerging in supermarket applications.

There is a wide range of commercially available technical papers, handbooks and case studies from industry bodies such as:

- American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), offer a wide range of publications including the 2006 Handbook for Refrigeration that is used by Australian refrigeration engineers;
- International Institute of Refrigeration (IIR), offer a wide range of technical publications;
- Institute of Refrigeration (IOR) in the UK who is very active in the supermarket sector with fluorocarbon refrigerant containment projects in association with the UK Carbon Trust; and
- Air Conditioning, Heating and Refrigeration Institute (AHRI), who offer standards and guidelines commonly used throughout the world.

5.7 Recommendations

5.7.1 Benchmarks

The use of benchmarks based on energy intensity indicators can be powerful tool in assessing the performance of facility with another, and to drive further investment in energy efficiency technology or practices. To take account of the diverse mix of interactive equipment, technologies and services within supermarkets, a storewide electricity consumption benchmark would appear the most appropriate indicator. This has an addition benefit in being easily measured and verified.

Recommendations include:

- The supermarket industry should be encouraged to adopt energy intensity benchmarks expressed in terms of total electricity consumption per store unit area per year (kWh/m^2 p.a.); where area is defined as trading floor or store area;
- Benchmarks should be designed to drive cost-effective investment in the supermarket industry over a sustained period of time. Therefore benchmarks should be set for intervals of not more than five years to 2020 or later;
- Given the concentration of ownership in the supermarket industry in Australia and New Zealand, it is feasible that that these benchmarks could be adopted as a voluntary agreement, with regular reporting arrangements to the E3 Committee;
- Should this prove difficult to negotiate or at the behest of the industry, these benchmarks should be adopted as regulations, which include requirements for regular reporting and verification;
- Table 31 provides the proposed initial benchmarks to be met by 2013 for categories of large, medium and small sized stores. These benchmarks were determined based information discussed in Section 5.4 and provided in Attachment 3, which includes quantitative data from a study of over 1,780 stores in the UK by the University of Bristol, local data from Cold Hard Facts study and published information from Corporate Responsibility Reports (Sustainability Reports) prepared by local and multi-national food retailers. It should be noted that the proposed targets of 820kWh/m^2 and 850kWh/m^2 p.a. for medium and large stores respectively equates to an improvement of around 10% on Woolworths stated average of 920kWh/m^2 for total electricity consumption in their stores in 2006;

Table 31: Proposed MEPS (kWh/m^2 p.a.) by store size

Category	Size of trading floor size (m^2)		MEPS Energy intensity (kWh/m^2 p.a.)
	Range	Average	
Large	≥ 2,750	3,800	820
Medium	≥1,500 and < 2,750	2,500	850
Small	< 1,500	650	980

- In order to determine future benchmarks, performance data provided by the major food retailers directly, or via the *National Greenhouse and Reporting Act 2007* (NGERS), should be analysed. This may also lead to a further refinement of the benchmarks to take into account the different effects of full service supermarkets versus stores with less refrigeration (for example a measure of the proportion of chilled and frozen Stock Keeping Units versus other merchandise) and stores with different air conditioning arrangements such as stand-alone or supplied by a shopping centre.

5.7.2 Open display cabinets

International trends suggest that ‘open freezers’ are already being replaced by those with doors or lids in Europe and the USA. Given the significant energy wastage from open display cabinets, it is time to transform the existing stock of display cases to 'closed door' cases or varieties with efficient air curtain arrangements with zero air spillage.

The key recommendations on display cases are:

- All new low temperature display cases to be horizontal 'coffin' style with sliding lids by 2012 (see
- Figure 68 and Figure 69 for illustrations of products commercially available) rather than vertical 'up-right' freezers that spill cold air into supermarket aisles when doors are opened;
- Existing low temperature display cases to have doors retro-fitted by 2015 with solid doors on vertical 'up-rights' and sliding lids on 'coffin' style freezers;
- New medium temperature refrigerators to have doors (either solid or high performance glass doors or efficient air curtain arrangements to create zero air spillage) by 2015;
- Existing medium temperature refrigerators to have night blinds by 2015 or to be replaced.

While these measures can be seen as complimentary to the MEPS regulations governing display cases (AS1731: 14), it recommended that these be adopted by the supermarket industry as a voluntary agreement.

As with the benchmarking recommendation, provisions for monitoring and verification will need to be included within any voluntary agreement.

Should this prove difficult to negotiate or at the behest of the industry, these benchmarks should be adopted as regulations, which include requirements for regular reporting and verification.

Figure 68: High efficiency horizontal 'coffin' style freezer with lids

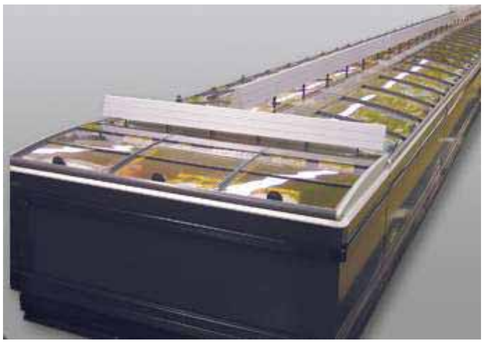


Figure 69: Self-contained high efficiency horizontal 'coffin' style freezer operating on natural refrigerants

5.7.3 Horizontal measures

Other energy saving contributions will come from horizontal measures proposed for components such as compressors, fans and the use of Variable Speed Drives (VSD) that are discussed in detail in Sections 3 and 4.

5.8 References

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Woolworths, 2008a	Woolworths Sustainability Report, 2008
Woolworths, 2008b	The Facts About Grocery Retailing at Woolworths, April 2008

Attachment 3: Supermarket benchmarks; energy and emission intensity

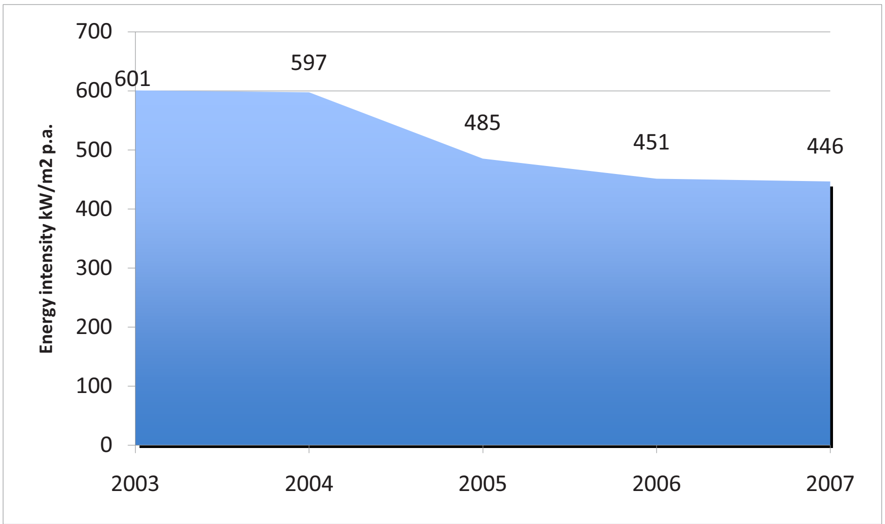
Ahold supermarkets

Ahold is an international group with supermarkets based in the United States and Europe that has been measuring and publishing energy intensity benchmarks since 2002. The energy intensities published in their Customer responsibility Reports (Ahold, 2002 to 2008) are summarized in Table 32 below. The European benchmarks are based on 'total store area' and the US benchmarks are mostly based on 'sales area only'. Figure 70 provides a graphical illustration that shows a downward trend in energy consumption of the average over all Ahold stores by more than 20% since 2003.

Table 32: Energy intensities (kWh/m^2 p.a.) of Ahold supermarkets from 2002 to 2007

	Measurement basis	2002	2003	2004	2005	2006	2007
ICA (Norway)	Total store area	-	600	650	580	568	556
ICA (Sweden)	Total store area	-	-	-	-	522	500
Central Europe Arena	Total store area	-	-	503	543	-	-
Stop & Shop (USA)	Total store area	-	607	602	591	868	821
Giant-Landover (USA)	Sales area only	878	714	715	711		
Giant-Carlisle (USA)	Sales area only	-	845	870	-	748	801
Tops (USA)	Sales area only	-	837	841	-	-	-
Average (All stores/regions)	-	-	601	597	485	451	446

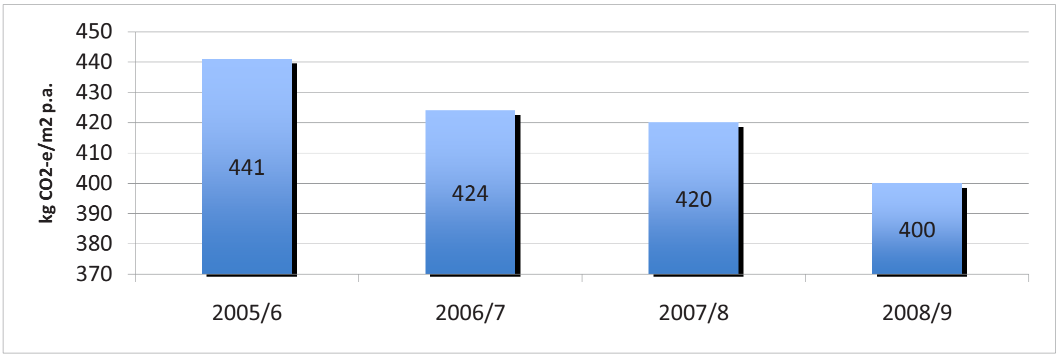
Figure 70: Average energy intensity (kW/m^2 p.a.) of all Ahold supermarkets from 2003 to 2007



Sainsbury's supermarkets

Sainsbury's have over 750 supermarkets in the UK and claim to be the first food retailer in the UK to publish a customer responsibility report, published in 1996. Sainsbury publish average store emission intensities in kg CO_2-e/m^2 per annum based on sales area that is illustrated in Figure 71. Sainsbury's claim to have an active energy reduction program which has resulted in a reduction of over 9% in kg of CO per m^2 of sales area against their 2005/06 baseline even with significant growth. The Carbon Trust in the UK lists the Greenhouse gas conversion factors for grid electricity of 0.537 kg CO_2-e per kWh. Sainsbury's purchase 10% green electricity, which has the effect of reducing the conversion factor to 0.483 kg CO_2-e per kWh. Using this conversion factor that allows for green energy, average energy intensities can be calculated with 913 kWh/m^2 p.a. in 2005/6 and 828 kWh/m^2 p.a. in 2008/2009.

Figure 71: Average emission intensity (kg CO_2-e/m^2 p.a.) of Sainsbury supermarket stores from 2005 to 2008.



University of Bristol study of energy consumption in supermarkets

A recent independent study undertaken by the University of Bristol into supermarket and food retailing involved surveying close to 50% of stores of the main supermarket chains in the UK (BU, 2008). The study specified energy intensity in kWh/m^2 per annum based on sales area and the results are summarized in Table 33. Figure 72 and Figure 73 provide scatter diagrams of the data collected for stores ranging from 280 to 1,400 m^2 and 1,400 to 5,000 m^2 respectively.

Table 33: UK energy intensity indicators in supermarkets and food retailing

	Size (m^2)	Sample size	Energy Intensity (kWh/m^2)	Standard deviation (kWh/m^2)
Mid-sized stores	280 to 1,400 m^2	1,360 stores	1,000 to 1,600	220
Large stores	1,400 to 5,000 m^2	420 stores	600 to 1,000	140

Figure 72: Energy intensity (kWh/m² p.a.) of food stores survey with sales areas from 280 m² to 1,400 m²

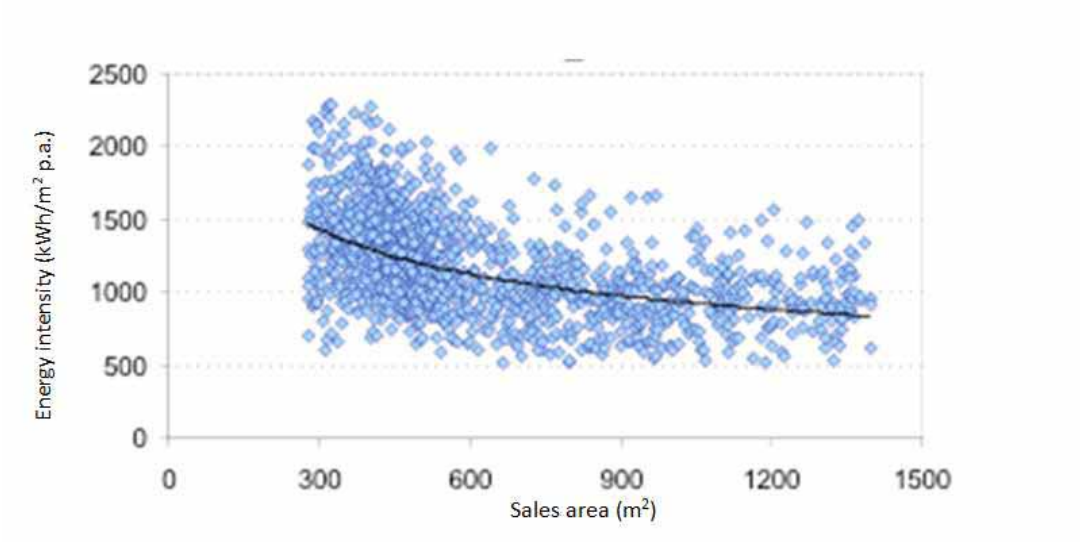
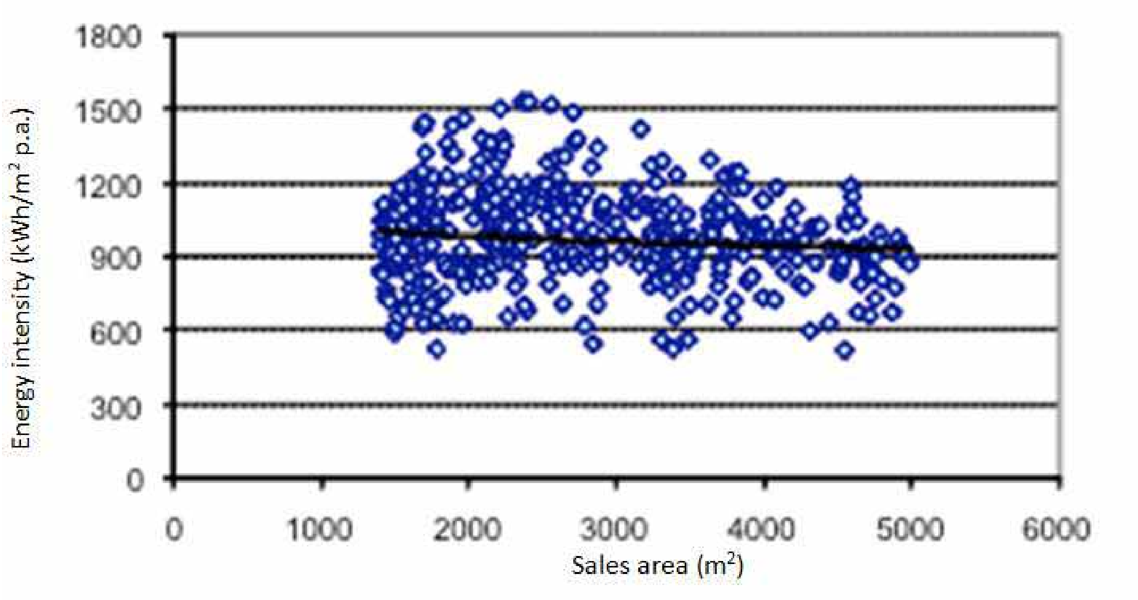


Figure 73: Energy intensity (kWh/m² p.a.) of food stores survey with sales areas from 1,400 m² to 5,000 m²



6 Walk-in Coolrooms

6.1 Introduction

Stand-alone walk-in coolrooms (WICs) consume an estimated 914 GWh of electricity per annum, which is equivalent to approximately 7% of total electricity used in Australia for commercial refrigeration. This estimate excludes WICs operating on central plant, such as in large distribution centres with cold storage facilities operating on industrial refrigeration systems and supermarket coolrooms that are often run from centralized compressor rack systems.

This section on WICs describes the main types of materials, equipment and accessories in common use, provides a market profile and estimates the electricity consumption attributable to refrigeration equipment in this sector. Significant energy reduction opportunities are identified and discussed. This section also reviews relevant Australian and overseas energy efficiency policies and identifies policy options for adoption in Australia.

6.2 Description of technology

A WIC is an insulated enclosure with similar operational principles to any refrigerator, but capable of storing significantly more goods. The term walk-in coolroom is used to describe an enclosed storage space that is either refrigerated to temperatures above zero degrees Celsius (walk-in-cooler), or is refrigerated to zero degrees and below (walk-in freezer). There are very specific performance parameters to ensure food quality and safety is not compromised. These parameters are prescribed in Australian Food Standards and can vary throughout the Cold Food Chain.

A typical WIC consists of the following components:

- Insulated panels constructed into a room with insulated walls and ceiling, the structure either mounted directly on a concrete slab or onto an insulated floor structure, with sliding door or air-curtain for access;
- Evaporator fan-coil (usually mounted near the ceiling in the room);
- Remote condensing unit (located outside); or,
- Drop in or slide in packaged unit (instead of evaporator and condensing).

Generally WICs are fabricated on site and are a customized product, although the prefabricated market is growing in size. Refrigeration is typically delivered through a forced-air evaporator located in the cooled space, coupled to an air-cooled condensing unit located externally.

WICs are used in a variety of applications mostly in the cold food chain by primary produces and food processors, facilities for cold storage distribution, in catering, hospitality and retail outlets.

Table 34 provides an overview of all WIC and cold storage dimensions, sizes and types of equipment. The focus of this analysis is on smaller WIC's up to 100 m^2 floor area and up to 4 m in height and excludes products designed and marketed exclusively for medical, scientific or research purposes. The larger refrigerated rooms used in major supermarkets; food processing and cold storage distribution are typically serviced by large central refrigeration systems and are discussed elsewhere in this report, although it should be noted that many of the energy saving opportunities noted here can be applied to larger facilities as well.

Table 34: WIC categories/nominal sizes, warehouses and types of refrigeration equipment

Description	Dimensions	Nominal capacity[16] (kWr at 5°C)	Type of refrigeration equipment
WIC: Mini	< 9 m^2 x 3 m high	2,250	Small condensing unit and evaporator or DISI packaged unit
WIC: Small	< 24 m^2 x 3 m high	4,100	Small to medium condensing unit and evaporator or DISI packaged unit
WIC: Medium	< 36 m^2 x 4 m high	9,000	Medium condensing unit and evaporator
WIC: Large	< 100 m^2 x 4 m high	20,400	Centralized plant (rack system) or large condensing unit)
Small warehouse	< 200 m^2 x 7 m high	See Section 7	Centralized plant (rack system)
Distribution centre	5,000 to 250,000 m^3	See Section 7	Centralized industrial refrigeration plant (ammonia)

(ES, 2007 and industry sources)

6.2.1 Structure (insulated walls or panels, doors and floor)

The 'structure' or refrigerated storage area is generally constructed from insulation panels (commonly known as sandwich panel) or in the case of larger WICs the insulation can be part of the structure of the building.

The large majority of medium temperature (above 0°C in storeroom) WICs are constructed from 75mm expanded polystyrene (EPS) with freezers using 100 to 150mm EPS. Most WICS are fabricated on site as a customized product to fit an internal space. The prefabricated market, where kits are imported from the People's Republic of China as a flat pack and supplied directly to customers to assemble is still relatively small due to high shipping costs and product specifications uncertainly.

Polyisocyanurate (PIR) has a higher thermal rating than EPS and is offered at a price premium of 30% or more depending on the thickness. The thermal property of insulation is generally expressed as an R-value in m^2K/W. The R-values specified by Bondor, one of the major suppliers of both products is 1.92 for 75mm EPS, 2.63 for 100mm EPS and 4.8 for 100mm PIR. The R-values for 150mm EPS is 3.95, which is similar to the R-value for 75mm PIR of 3.6. PIR is starting to be used on large WICs or warehouses predominately due to its fire rating properties.

Polyurethane insulation (PUR) is rarely used on WICs, however can be found on many other commercial refrigeration applications including insulation on truck refrigeration containers and refrigerated display cabinets (ES, 2008). PUR is manufactured using a HCFC foam blowing agents (typically HCFC-141b) which are ozone depleting substances that are being phased out under the Montreal Protocol.

WICs used in retail and hospitality applications often have glass doors or windows for merchandising purposes. Depending upon the type of glass (single, double or tripled glazed with either heat-reflective or gas filled glass), doors (simple strips, spring hinged or other method of minimizing infiltration when

[16] A useful 'rule of thumb' used by industry for checking nominal capacity of cool-rooms is 250 to 300 kWr per m^2 on WICs with heights of 3 to 4m and 100 W per m^2 in large distribution centres with heights of 12m or more.

doors are open) and anti sweat devices to stop glass from fogging up, there can be a significantly impact on energy consumption.

6.2.2 Evaporator fan-coils and remote condensing units

The storage area is commonly refrigerated using one or more evaporator fan-coil(s) with a remote condensing unit. Most WICs are customized both to the site and the task, which requires calculating the refrigeration heat load and selecting and matching an evaporator and condensing unit to satisfy the temperature to be maintained and specific requirements of the application. The design process has to take into account the type of produce, display doors used (if in a retail environment) and the pattern of usage.

Standard fan coil units (evaporators) are used in WICs; however low profile models (see Figure 74) that take up less storage space are preferred in certain applications. The remote condensing units are typically conventional air-cooled units that require a cover when mounted outdoors or packaged. These condensing units operate on HCFC or HFC refrigerants with hermetic (reciprocating or Scroll) or semi-hermetic compressors. Both types of air-cooled condensing units are illustrated in Figure 75 and Figure 76.

Figure 74: WIC categories/nominal sizes, warehouses and types of refrigeration equipment

Figure 75: Conventional air-cooled condensing unit

Figure 76: Packaged air-cooled condensing unit

(Source: Heatcraft)

6.2.3 Drop-in and slide-in packaged units

Drop-in and slide-in (DISI) packaged units are complete self-contained refrigeration systems specifically designed for WIC applications. They offer an all-in-one package (evaporator, condensing unit and controls with 3-pin plug and lead on single-phase units) for easy installation by refrigeration or non-refrigeration trades.

Drop-in units have the condensing units mounted on a base or insulated plug with the evaporator underneath and are provided with a template to cut a hole in the ceiling of the WIC to locate the unit from above. Slide in units are typically used when there are height restrictions above the WIC and the plug is inserted from the side.

DISI packaged units are used on low and medium temperatures applications and smaller WICs (up to 24 m^2 x 3 m high or nominal capacity of 4,100W at 2°C evaporator temperature). Figure 77 and Figure 78 provide illustrations of both configurations.

Figure 77: Low profile drop in packaged unit

Figure 78: Slide in packaged unit

(Source: Bresco distributor of Zannotti)

6.3 Market profile

6.3.1 Coolroom stock and sales

WICs are used extensively throughout the food chain to refrigerate fresh, chilled and frozen produce. The flow of produce is illustrated in by the Refrigerated Food Chain in Figure 1 in Section 1 where goods pass from farm gate to food processors, then to cold storage for distribution to catering, hospitality and retail outlets. The existing stock of WICs in Australia is estimated to be 64,000, or 2.8 per 1,000 people. This estimate builds on data collected for *Cold Hard Facts* (ES, 2007) with more detailed research in the catering and hospitality segment and data from the Sustainability Victoria *Catering Equipment Study* (SV, 2008). Analysis by Natural Resources Canada drew similar conclusions: finding a total of 96,000 WICs or 2.9 per 1,000 people based on similar definitions with around 3,300 new or replacement units sold each year in Canada (NRC, 2009a).

Sales of new WICs in Australia are estimated to be 2,300 per annum, of which 1,300 are powered with DISI packaged units and the balance by evaporators and condensing designed for the application. The average life-span of the structure is 10 to 15 years although the major items of equipment do not last as long. There is little known about the size of the second-hand market that re-cycles WICs for the catering and hospitality industry; however in these instances the life of the WIC structure would be extended. The estimated stock of WICs per segment and nominal sizes is provided in Table 35 and Figure 79.

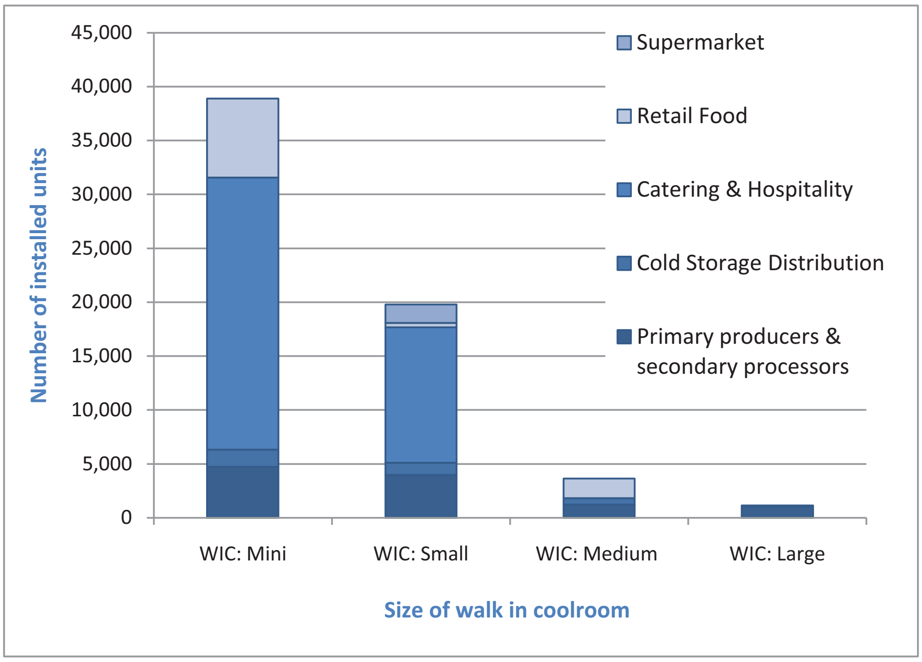
WICs generally range in size from 1.8 x 1.8 x 2.4 m high to 100 m^2. Beyond this size cool rooms are typically freestanding structures that are classified as Cold Storage facilities in this study and are discussed in Section 7.

Table 35: WIC per segment and size (excludes WICs operating on central plant)

Description	Dimensions	Primary producers & secondary processors	Cold Storage Distribution	Catering & Hospitality	Retail Food	Super market	Total
WIC: Mini	< 9 m^2 x 3 m high	4,733	1,578	25,248	7,312	-	38,871
WIC: Small	< 24 m^2 x 3 m high	3,964	1,133	12,557	420	1,699	19,773
WIC: Medium	< 36 m^2 x 4 m high	1,214	606	-	1,820	-	3,640
WIC: Large	< 100 m^2 x 4 m high	1,011	-	-	140	-	1,151
Total		10,922	3,317	37,805	9,692	1,699	63,435

(Source: Updated ES, 2007 data with assistance from industry sources)

Figure 79: WIC per segment and size



6.3.2 Coolroom applications: catering and hospitality

The majority of WICs (around 60% of stock by quantity) are used in food service environments to provide bulk storage for commercial kitchens involved in catering and hospitality. There are over 50,000 commercial kitchens servicing restaurants, pubs, clubs, motels, function centres, caterers and some café's that have WICs. The numbers of catering, hospitality, institutional and retail outlets where WICs are found are listed in Table 36.

Table 36: Number of institutional and commercial catering and hospitality venues

Type of venue	Segment	Venues
Hospitals	Institutional	1,011
Nursing home		2,844
Tertiary institutions		803
Schools		7,954
Work canteens/private		1,264
Government canteens		243
Total institutional		**14,119**
Restaurants	Catering and hospitality	15,142
Cafes		7,091
Hotels/motels		9,132
Clubs		4,203
Caterers		1,012
Function centres		832
Total commercial		**37,412**
Total hospitality and catering		**51,531**

(SV, 2009, ABS 8165.0, 2006 and ES, 2007[17])

WICs in food service applications are generally smaller as these venues often contain an extensive range of other refrigerating devices including 1, 2 or 3 door upright, under bench and bar fridges; fridge/freezer combos; and 1, 2 or 3 door upright, under bench and chest freezers. The high proportion of WICs in catering and hospitality applications and the additional refrigeration devices explains why an estimated 60% of WICs are less than 9 m^2. Other catering applications where WICs can be found are in institutional outlets providing bulk storage for kitchens used to provide services to hospitals, educational facilities and canteens.

6.3.3 Coolroom applications: food retailing

WICs are required in a variety of retail food applications as part of preparation and storage produce prior to being sold to consumers as fast food, beverages or groceries. WICs can be found operating off individual condensing units in some small to medium supermarkets; however the majority are found in other food retail outlets that are listed in Table 37.

[17] Estimates for the number of hospitality, catering and food retail outlets were based on a compilation of data from SV, 2009, ABS 8165.0, 2006 and ES, 2007. This data excludes 'non-employing' enterprises as they are less likely to have a WIC. All data was adjusted with 1.5% growth per annum to harmonize 2009 estimates.

Table 37: Number of food retail outlets

Type of outlet	Segment	Outlets
Grocery/Convenience Stores Only	**Retail food and beverage**	3,799
Fast food/take-away		15,165
Automotive Fuel Retailing		4,030
Fresh Meat Fish & Poultry Retailing		3,907
Fruit & Vegetable Retailing		1,839
Liquor retailing		1,400
Total retail food		30,140

(SV, 2009, ABS 8165.0, 2006 and ES, 2007)

WICs are commonly found in fast food franchises such as McDonalds, Hungary Jacks and Red Rooster. Convenience stores such as 7 Eleven and automotive retailers have WICs mostly for beverages and milk. There is a variety of independent meat and green grocery retailers that typically have medium sized WICs to stored perishable foods to extend their shelf life. Chilled bulk storage, often with glass doors, is required for liquor retailing of packaged beverages. Some liquor retailers such as Dan Murphy can have cold storage areas up to 100 m^2 or more to store large quantities of chilled beverages.

6.3.4 Coolroom applications: primary producers, processors and distribution

WICs used by primary producers are often located in dusty and sometimes very hot situations inside steel sheds. When produce is being harvested, washed, boxed and stored, primary producer coolrooms have to cope with large volumes of traffic. However there may be weeks or possibly months between the sale of produce and next harvest when these coolrooms are very lightly used, if at all. Common primary producer applications include:

- Fruit farmers (apples, oranges, peaches, pears, grapes are often small to medium warehouse);
- Vegetable growers (specialty such as broccoli, mushrooms, etc.);
- Poultry farmers for eggs or chickens if they are also a processor;
- Seafood and aquaculture, and
- Specialty applications such as bulbs and flowers.

Primary producers and food processors are estimated to employ less than 20% of WIC stock in service by quantity. Major food processors may have some WICs but often have larger warehouse installations, while gourmet food or small to medium niche market processors use WICs. Food processing activities that are heavy users of refrigeration storage include:

- Dairy processing (cream, cheese, yoghurt, ice-cream and pasteurizing);
- Maturing rooms (cheese, salami);
- Bakeries to retard tempering of dough prior to batch cooking;

- Cooling and drying rooms for nuts prior to packing;
- Beverages (orange or apple juice, grapes from vineyards);
- Processed food (pasta rooms, pastries);
- Frozen foods (pizzas, pre-prepared meals, meat pies);
- Abattoirs, meat processing and packaged gourmet meats (crumbed, marinated, cryovac);
- Poultry processors; and
- Confectionary.

The cold storage and food distribution chain mostly involves very large storage facilities; the WICs found in this segment are mostly for specialty applications and small operators. This is particularly the case with specialty seafood businesses and importers/distributors of gourmet and deli foods that deal direct with retailers. It is estimated that approximately 5% of the stock of WICs are found in the cold storage and food distribution chains.

6.4 WIC, refrigeration equipment and insulation suppliers

The large majority of WICs are custom built and supplied by coolroom specialists or refrigeration contractors. These contractors source the commercial refrigeration equipment from refrigeration wholesalers such as Heatcraft, Actrol, Airefrig and smaller independents.

The main brands of DISI packaged units are Kirby (supplied by Heatcraft), Bromic and Zannotti. The two major national suppliers of insulation panel are Bondor and Kingspan. Kingspan only supplies PIR and Bondor supplies both EPS and PIR insulation panel. Most other insulation panel suppliers are members of the EPS Panel Group of Australia, which is a working group within the Plastics and Chemicals Industries Association (PACIA). Some of the major participants are Austral Insulation, Burton Coolrooms, Polypanel industries, Retracom and United Panel Industries. Chemical companies such as BASF and Huntsman Chemicals that supply the foam blowing agents and ingredient have an interest in this sector as well.

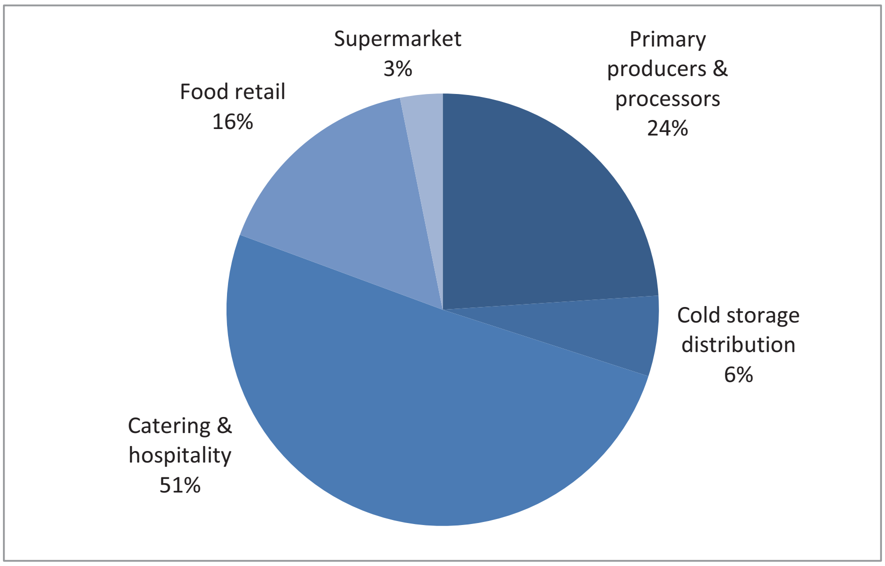
6.5 Energy consumption and greenhouse gas emissions profile

WICs consume an estimated 914 GWh of electricity per annum, which is equivalent to approximately 7% of total electricity used in Australia for commercial refrigeration. Table 38 provides a break-down of the energy use and emissions of WICs not operating on central plants. The energy use was calculated by selecting medium temperature condensing units with matching evaporators for respective room sizes and assuming equipment operated 16 hours per day, all year round. The input watts were checked against the industry rule of thumb of 250 to 300W of refrigeration capacity per m2 with a system COP of 2.5. A further adjustment of 10% was made to compensate for additional energy consumption of low temperatures system. This adjustment was consistent with estimates by Natural Resources Canada for average size WICs of 15 m2 consuming 16,200 kWh per annum on medium temperature and 21,400 kWh per annum on freezers (NRC, 2009). Assuming 30% of WICs are freezers, the weighted average energy consumption of 17,760 kWh per annum is 10% higher than medium temperature of 16,000 kWh. Figure 80 provides a pie chart for each the main application sectors, which shows more than half of the energy consumed is in catering and hospitality applications. The Greenhouse gas emission factor used to calculate emissions was 1.007 Kg CO2-e/kWh, which is a weighted average (based on state population) of the NGERS state based full fuel cycle indirect emission factors for consumption of purchased electricity from the grid (DCC, 2008).

Table 38: Energy use by refrigerated coolrooms in Australia, 2009

Description	Proportion of total	Electricity Consumption (GWh p.a)	Emissions kt CO_2-e
WIC: Mini	42.5%	388	391
WIC: Small	36.5%	333	335
WIC: Medium	13.0%	118	119
WIC: Large	8.0%	75	76
Total		**914**	**920**

Figure 80: Energy use by refrigerated coolrooms by application



6.6 Opportunities for improving energy use

There are a number of opportunities to reduce the electricity consumed by WICs; each one of which will incrementally and independently reduce the compressor load and energy consumption. The key opportunities are listed below:

- Improved thermal specification of walls (insulation panels), glass and floors;
- High-efficiency refrigeration compressors;
- High-efficiency evaporator and condenser fan motors;
- Reduce the industry practice of over sizing refrigeration equipment;
- Anti-sweat heater controls that sense humidity;
- Energy efficient defrost controls;

- Proper construction of structure including sealing corners and joins of insulation panels, types of doors and door gaskets;
- Energy-efficient interior lighting; and
- Effective and regular cleaning of fans, coils and maintenance of seals, hoses, pipes and machinery.

6.6.1 Thermal specification of walls, glass and floors

The large majority of the WIC existing stock is constructed from 75mm expanded polystyrene (EPS) insulated panel (sandwich panel). There are two suppliers Bondor and Kingspan who offer polyiscyanurate (PIR) sandwich panel with higher thermal properties. The thermal property of insulation is generally expressed as an R-value in m^2K/W. The are R-values of EPS and PIR can vary from supplier to supplier and thickness, however a general R-value for 150mm EPS is 3.95, which is similar to the R-value for 75mm PIR of 3.6. The market has largely rejected PIR panel due to the higher pricing (20 to 30% more than standard 75mm EPS and a greater premium with increasing thickness). The premium capital cost of PIR is a significant obstacle to greater market penetration because it appears to be coupled with very poor knowledge of the environmental benefits and short paybacks that can be achieved with this material.

Table 39 and Figure 81 show the potential energy savings from the use of improved insulation materials in WICs, resulting from a series of heat load calculations undertaken for a range of popular sizes and configurations of WICs with varying usage (door openings). Further details of this analysis are included in Attachment 5.

Table 39: Heat load analysis, 75mm EPS versus 100mm PIR

Heat-load calculation	Dimensions w x l x height (m)	Usage (Medium/ high)	Door type (Solid/glass/ double glazed)	Room load (W)		
				75mm EPS	100mm PIR	% Reduction energy consumption
1. a)	1.8 x 1.8 x 2.4	Medium	Solid	608	411	32%
1. b)		High	Solid	862	656	24%
1. c)		High	Glass	1,621	1,455	10%
1. d)		High	Double glazed	1,142	976	15%
2.	3 x 3 x 2.4	Medium	Solid	1,101	749	32%
3.	6 x 4 x 3	Medium	Solid	2,297	1,522	34%
4.	6 x 6 x 4	Medium	Solid	3,445	2,237	35%
5.	10 x 10 x 4	Medium	Solid	6,740	4,363	35%

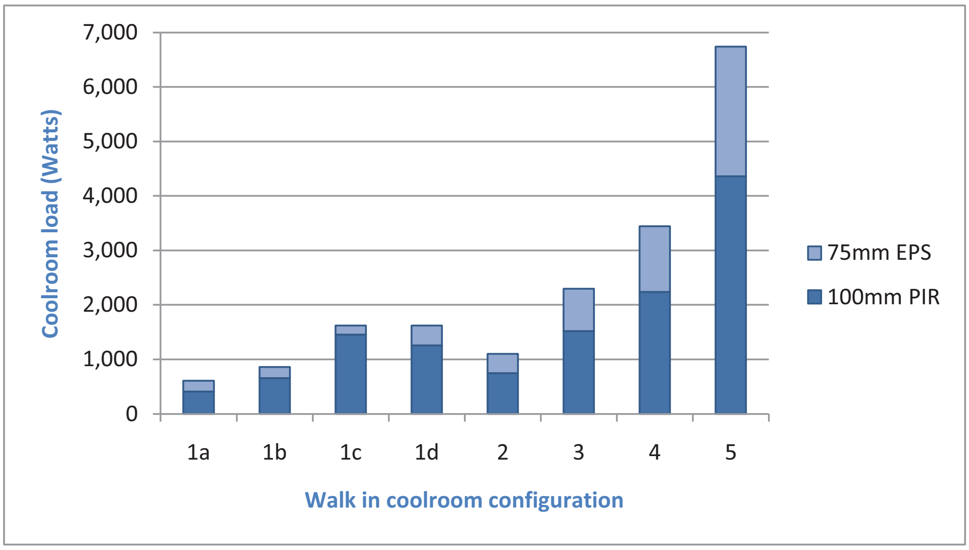
(Refer Attachment 5 for more details)

Assumptions for heat load calculations:

- Medium temperature WIC at 5°C;
- Usage (frequency of door opening) medium and high;
- Run time of 24 hours per day, 365 days per annum;

- Simulated room load only with no electrical or miscellaneous loads;
- 1 Kelvin temperature difference (1 KTD), with ambient temperature of 35°C;
- K factors for insulation (EPS is 0.0385 and PIR 0.021 W/m K);
- Floor insulation based on 100mm thick concrete;
- Glass door dimensions (1.8 x 1.8 x 1.8 high) on one wall, calculation number 1.c) was based on single glazing and 1.d) on double glazing.

Figure 81: Calculated power savings from higher insulation levels, 75mm EPS versus 100mm PIR



(Refer Attachment 5 for more details)

The analysis found an average reduction in refrigeration load of 14% when comparing 75mm EPS to 100mm EPS on WICs with solid doors. The energy savings were more significant when comparing 75mm EPS to 100mm PIR, which resulted in an improvement of more than 30%.

Glass makes a substantial difference to the energy consumption. Refrigeration load more than doubles with single glazed glass on one wall. The increase in load can be significantly reduced with double or triple glazing, with the results showing a 30% reduction with double-glazing. The analysis did not evaluate the impact of different floor types with varying insulation properties. In practice the floor insulation is only considered in freezers where losses through the floor are significant.

It is clear the energy consumption from WICs would significantly benefit from improvements to the thermal properties of insulation panels, glass doors and flooring. Measures that migrate the existing stock of WICs to 100mm PIR and improve the thermal resistance of glass and floors could conservatively achieve a 20% reduction in energy consumption from the national stock of WICs, a saving of around 180 GWh per annum.

The capital and energy costs of switching from 75mm EPS to 100mm PPR insulation have been modelled for four sizes of WICs and likely payback periods range from 3.5 to 5 years, depending upon the discount rate assumed. This analysis is discussed in detail in Section 6.6.6.

6.6.2 High-efficiency compressors and fans

High-efficiency refrigeration compressors use more-efficient electric motors and have lower compressor losses. These losses (in the form of heat) are an additional load for the refrigeration system, and the use of high-efficiency compressors can save more than 10% in energy costs, this is explained in more detail in Section 3.

Similarly, high-efficiency motors on evaporator fans release less heat into the refrigerated room than conventional induction motors. This reduces the energy draw by the fan motor and the compressor. System energy savings can be from 5 to 10% (NRC, 2009b). High-efficiency condenser fan motors can also reduce energy requirements, although system energy savings are less for these motors because they operate outside the refrigerated compartment. In addition, further savings are available from improvements to operational efficiency through regular maintenance.

6.6.3 Over sizing refrigeration equipment

When designing cooling and freezer systems, the most important parameters are refrigeration heat load, and processing time to maintain desired food safety and quality standards. The heat load calculation determines the capacity of the refrigerating equipment (compressors, condensers and evaporators) and the energy consumption.

The heat load assessment takes into account the temperature to be maintained, the type of produce, the WIC thermal insulation including display doors or windows and the access requirements (high, medium or low usage). Some contractors determine heat load based on experience or ‘rules of thumb’, where designs are typically based on 250 to 300 kWr per m^2. The preferred method is using industry based software that calculates refrigeration loads such as Heatcraft Heat-load Software used to calculate refrigeration loads for various WIC configurations in Attachment 5.

Over-sizing system design capacity (condensing unit and evaporator output requirements) relative to actual loads has a major impact on energy consumption, as the larger equipment consumes more electricity and affects the time that the evaporator fans operate at low speed.

Over-sizing is a common occurrence for a number of reasons. Engineers, equipment suppliers and contractors are primarily motivated to ensure that the system works adequately and are inclined to add a safety factor to guarantee system performance. For example, Heatcraft heat-load software adds a 10% safety margin onto the refrigeration load result (see Attachment 5) and then when matching condensing units to evaporators, contractors will often select the next size up. The need (for health reasons) to cool the product from room temperature to the required storage temperature within a short period of time is also met by installing sufficient overcapacity. These split incentives and conservative engineering practices tend to override consideration to minimize energy consumption.

To overcome the effects of over-sizing, standard methods of calculation or benchmarks are being considered. In the UK Department for Environment, Food and Rural Affairs (DEFRA) is considering a measure of energy consumption per cubic meter (energy intensity of WIC) or a ‘whole’ system index. The US Department of Energy is planning to introduce similar performance measures and test procedures, probably based on computer modelling.

There is no empirical data available that estimates the extent of over-sizing of WICs in Australia. It is conservative to suggest measures to improve or eliminate this practice could reduce energy consumption by 10% or more.

6.6.4 Anti-sweat heater and defrost controls

Glass display doors have anti-sweat heaters around them to keep external surfaces free of condensation during high humidity conditions. The heaters are usually on all the time, but they may not be needed in drier weather. Anti-sweat heater controls that sense humidity can be added and set to turn heaters off when not needed.

Energy-efficient defrost control systems eliminate unnecessary defrost cycles. Ice builds up on the evaporator coil during compressor operation, creating an insulating layer that reduces heat transfer through the evaporator coil and increases the load on the compressor; resulting in a more inefficient system. Frost must be removed by heating during a defrost cycle, which is usually initiated by a timer, whether needed or not.

The most effective controls are 'demand' defrost controls, which initiate defrosting in a variety of ways, such as by measuring the temperature or pressure drop across the evaporator, by measuring frost accumulation and by sensing humidity. All of these methods are more effective than using a simple timer to initiate defrosting.

Improved techniques and controls to remove ice from evaporators while keeping external glass surfaces clear can save 5 to 10% of total energy consumption.

6.6.5 Construction and sealing of structure

Maintaining a proper vapour seal, minimizing unnecessary door usage and effectively managing the coolroom pressure are important energy management considerations with WICs.

The structural integrity and proper sealing of the WIC structure in corners, joins of insulation panels and penetrations (piping or electrical) and selection of types of doors, door gaskets and floor finishes are essential to minimize ambient air/moisture ingress into the coolroom. The function of the refrigeration system is to maintain set point conditions inside the coolroom and outside air/moisture ingress either by door openings or through poor vapour sealing adds to the refrigeration load required to cool the refrigerated space. This 'unseen load' adds to the refrigeration system run time and the moisture presents itself as frost or dew on the evaporator coil that requires additional energy to collect, defrost and dispense of the moisture to the condensate drain.

During defrost cycles, the air pressure inside the WIC increases as the air heats up and expands, which can lift gaskets or can cause frosting around joints and eventually break down the vapour sealing of poor joints. Pressure relief port(s) are an important feature (particularly on freezers with greater defrost requirements) to effectively manage the internal coolroom pressure and minimize deterioration of vapour seals, which leads to additional energy usage. In their simplest form, pressure relief ports consist of a spring-loaded flap sized for the coolroom volume and defrost duties that can be heated for below zero ^{o}C applications.

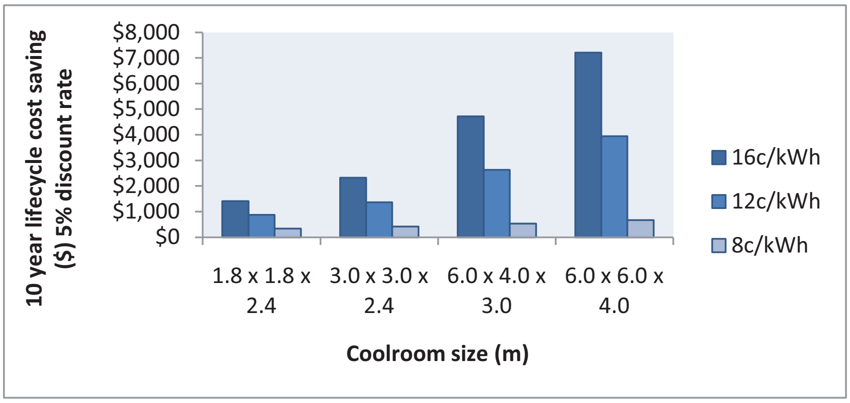
6.6.6 Cost-benefit analysis

To estimate the financial implications of energy efficiency measures identified in Figure 81 and Attachment 5, the capital and energy costs of switching from 75mm EPS to 100mm PPR insulation have been modelled for four sizes of WICs. This life-cycle cost analysis over a ten year period is based on the cost of insulation materials and the costs of refrigeration equipment provided by Australian suppliers. Importantly, the impact of the added insulation in reducing the cooling load allows for smaller capacity compressors and evaporators, which is reflected in lower capital costs for this equipment.

All of the results show a positive cash-flow over the 10 year period, however, as shown in Figure 82, the extent of overall savings are dependent upon the assumed price paid for electricity. Values of 8, 12 and

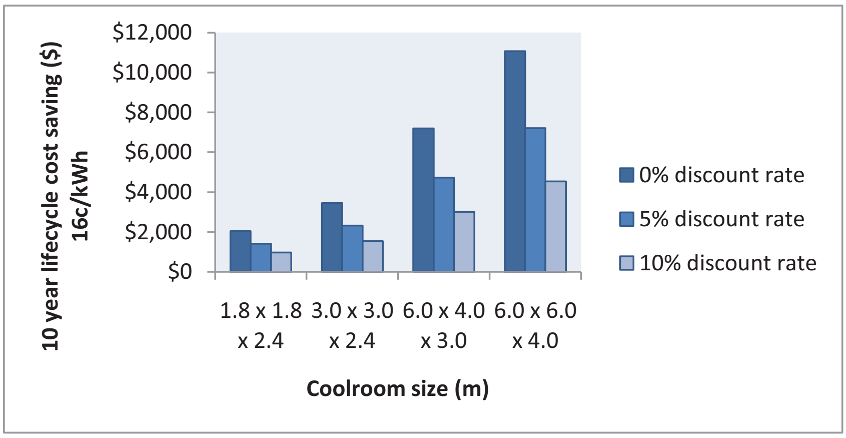
16 cents/kWh were modelled to reflect the range of prices found amongst commercial customers operating WICs. It should be noted that most customers have been experiencing price rises in recent times and many now pay a rate towards the top end of this scale.

Figure 82: Estimated 10 life-cycle cost savings at 5% discount rate as a result of switching from 75mm EPS to 100mm PIR insulation



Savings estimates are also highly dependent on the assumed discount rate, as shown in Figure 83.

Figure 83: Estimated 10 life-cycle cost savings at 0%, 5% and 10% discount rate as a result of switching from 75mm EPS to 100mm PIR insulation



Under the least favourable conditions (10% discount rate and low electricity prices), the payback for the investment in insulation is between 8 to 10 years. However, under more realistic electricity price scenarios, the payback period is being reduced to between 3.5 to 5 years, depending upon the discount rate assumed. These results are shown in Figure 84, Figure 85 and Figure 86 for the four sizes of WICs.

Figure 84: Estimated 10 life-cycle costs at 10% discount rate as a result of switching from 75mm EPS to 100mm PIR insulation (16c/kWh

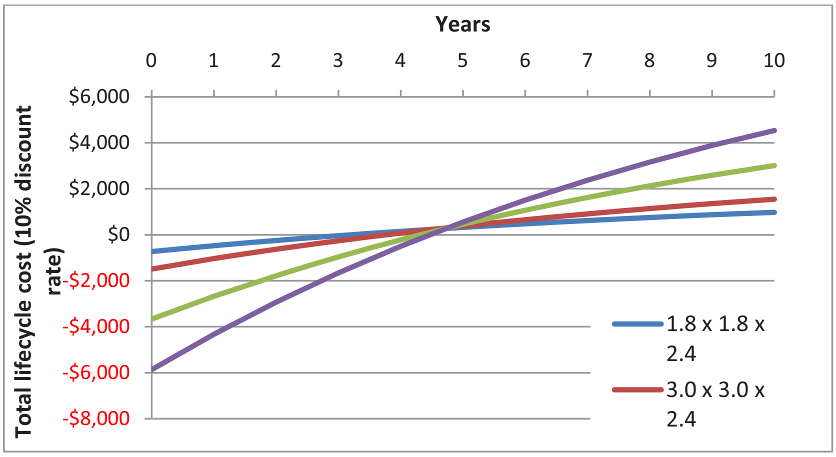


Figure 85: Estimated 10 life-cycle costs at 5% discount rate as a result of switching from 75mm EPS to 100mm PIR insulation (12c/kWh)

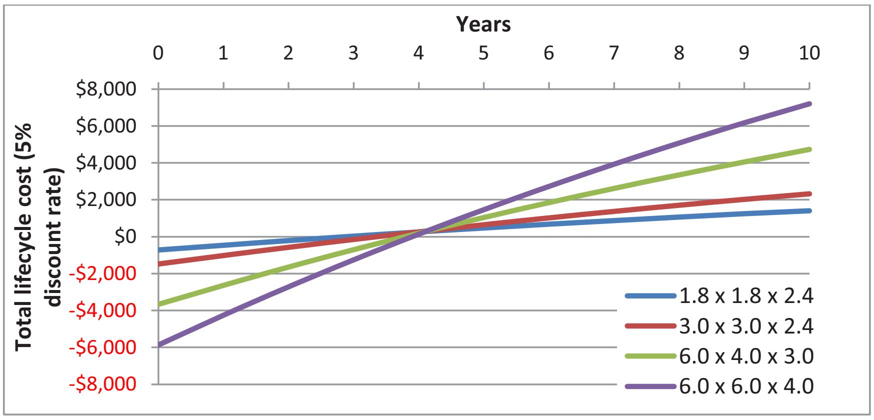
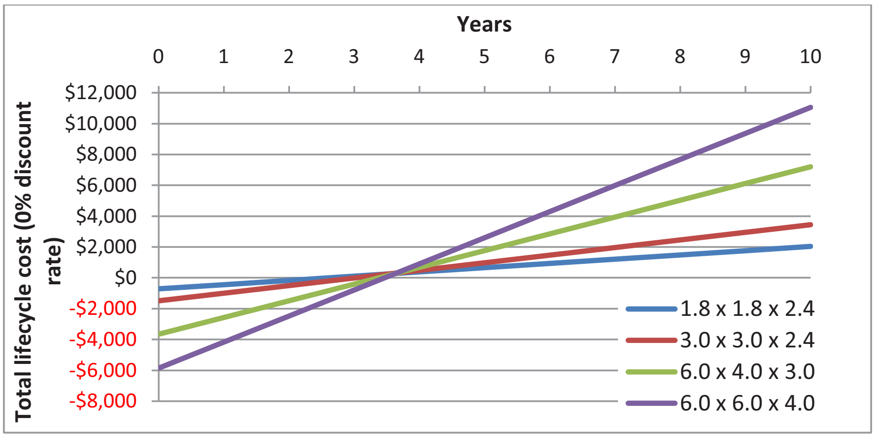
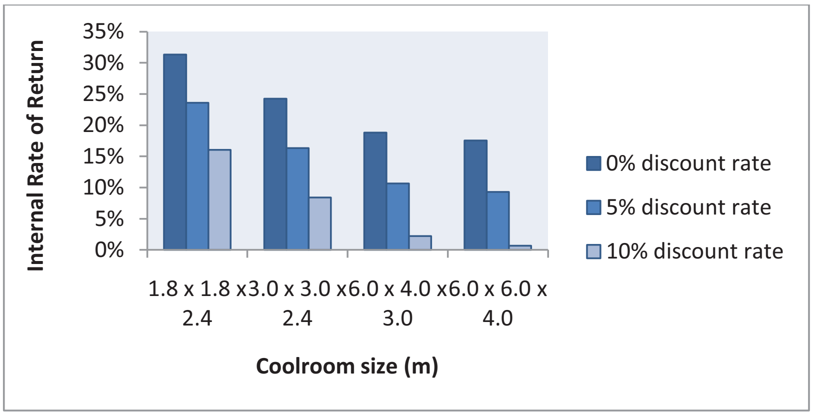


Figure 86: Estimated 10 life-cycle costs at 0% discount rate as a result of switching from 75mm EPS to 100mm PIR insulation (16c/kWh)



These scenarios demonstrate that investment in energy efficiency can generate significant rates of return. At a 5% discount rate and 16 cents/kWh, the internal rate of return can reach more than 20%, while at a zero discount rate the IRR may be more than 30% (see Figure 87).

Figure 87: Internal rate of return as a result of switching from 75mm EPS to 100mm PIR insulation (16c/kWh)



Nevertheless, constraints on investment capital and the continued existence of low electricity tariff rates for some customers are deterrents to investment in energy efficiency even amongst those that are aware of the opportunities.

6.7 Australian standards

There are no Australian Standards specifically for WICs; however certain aspects are covered in the Building Code of Australia (BCA) and food standards, including:

- AS 1366, Parts 1 to 3-1992 and Part 4-1989, Physical properties of rigid cellular polystyrene (EPS), polyisocyanurate (PIR) and polyurethane (PUR), which sets out minimum properties for six classes (compressive stresses, cross breaking strength, water vapour ingress, dimensional stability, flame propagation characteristics and thermal resistances for a 50mm thick sample at 25°C) and methods for determination and compliance;
- *AS 1530-2007 Methods for fire tests on building materials, components and structures*, which is mostly related to methods to simulate fire hazards and determine fire ratings;
- *Food Standards Australia Chapter 3.2.2 Food safety practices and general requirements.* This standard sets out how food should be received, stored, processed, displayed, packaged, transported, disposed of and recalled;
- AS/NZS 4859.1:2002 Materials for the thermal insulation of buildings - General criteria and technical provisions, supersedes AS 2464.5 and AS 2464.6 Methods of testing thermal insulation. These standards set out the method for determining the steady-state thermal transmission properties by means of the heat flow meter or guarded hot plate.

The thermal properties of insulated panels or structures used on WICs are of great interest as it significantly impacts on the sizing of refrigeration systems and energy consumption. There are no building directives under the BCA that prescribe MEPS or high efficiency standards for thermal insulation of WICs (BCA, 2009).

6.8 Overseas policies and standards

6.8.1 North America

The energy performance of walk-in coolers and walk-in freezers have been regulated in the United States since 1 January 2009 under the Energy Independence and Security Act of 2007 (EISA), section 312 (DOE, 2007). This specifies design requirements for individual elements such as for insulation levels and equipment. The legislation foreshadows that by 2012 overall performance standards WICs will be introduced.

Manufacturers of these products on-site need to ensure that, whatever components may be used in the construction of a walk-in cooler or walk-in freezer, the finished installation ultimately satisfies, as a whole unit, the design requirements in EISA.

The key definitions and measures in the standard are:

- Applies to all WIC less than 280 m^2;
- Minimum thermal insulation ratings wall, ceiling, and door with an R-value of at least 4.4 m^2K/W on coolers (equates to 100mm PIR) and 5.6 m^2K/W (thicker than 100mm PIR);
- Minimum thermal insulation ratings on floors of at least 4.9 m^2K/W;
- Automatic door closers that close to within 25.4mm of full closure, except doors wider than 1,143mm or taller than 2,134mm;
- Must have strip doors, spring hinged doors, or other method of minimizing infiltration when doors are open;
- Transparent doors or windows on medium temp (above 0^{o}C) WICs to have double-glazing and freezers (0^{o}C and below) triple-glazing;
- All single-phase fan motors on condensers and evaporators must be ECM (electric commutated motors); and
- Maximum power draw limits on anti-sweat heaters without heat controls.

For a more comprehensive list of measures see Attachment 4.

There are currently no Canadian regulations MEPS for WICs. Natural Resources Canada offer guidance on opportunities to reduce refrigeration loads and claim that high-efficiency options can be specified when ordering new units or when retrofitting existing units (NRC, 2009c).

6.8.2 Europe

The European Commission DG TREN, '*Preparatory studies for Eco-design Requirements of Commercial Refrigerators and Freezers*,' published in December 2007, explains that coolrooms are covered by the 'Building Directive' (2002/91/EC) and not by the 'Machinery Directive' (89/392/EEC) such as for other refrigerated products (EC, 2007). Where the term 'machinery' covers any equipment, whether for domestic, commercial or industrial applications, that has parts actuated by a power source other than manual effort. Therefore there are no MEPS or efficiency standards for WICs in the European Union.

In the UK, the Department for Environment, Food and Rural Affairs (DEFRA) prepared a policy brief in 2008 to explore opportunities of improving the energy performance of commercial refrigeration products. In this study there was interest in a measure of energy consumption per cubic meter (energy intensity of WIC) and a 'whole' system index (DEFRA, 2008). These targets have not been set or implemented.

6.9 Policy options

Despite evidence that there are substantial cost effective opportunities to improve the energy performance of coolrooms, the customer focus on minimising capital costs and entrenched industry practices have impeded the uptake of these options.

Given that better insulated and controlled refrigerated coolrooms are likely to facilitate compliance with food safety requirements as well as reducing energy consumption, it is important for governments to introduce policy measures which will ensure improved outcomes. The general types of policies that may be considered by governments in this case include:

- Industry training;
- Customer information (e.g. via a website);
- Voluntary energy labelling;
- Mandatory energy labelling;
- Minimum energy performance standards, and
- Market based incentives.

The policy aim and attributes of these are summarized in Table 40.

Table 40: Aims and attributes of policy options

Policy Measure	Policy Aim	Pros	Cons
Industry training	Change industry practices such as over-sizing. Pass on best practice to customers	Potential long-lasting impact	Doesn't address customer preferences directly Uncertainty of outcomes Slow-acting
Customer information	To highlight to customers how to specify the best performing products and practices	Relatively simple and inexpensive Can focus on good design and installation practices	Targeting difficult because of quantity and diversity of potential users Uncertainty of outcomes
Voluntary labelling	To highlight to customers the best performance products on the market	Relatively simple and inexpensive	Relies upon consumer awareness of the label Requires industry support Does not address first-cost issue Uncertainty of outcomes
Mandatory labelling	To enable customers to compare the energy performance of different products	Provides more information than other similar options	Relies upon consumer awareness of the label More expensive than other information options Does not address first-cost issue Uncertainty of outcomes
Minimum energy performance standards	To remove the worst performing products from the market.	Promotes competition on a level playing field Proven to be effective Certainty of outcomes	Probably the most expensive option
Market based incentives	To reduce the capital cost of an efficient product - typically to make it cost-effective	Tackles increased upfront investment Attracts attention	May reduce split incentive issues Uncertainty of outcomes Can be expensive

While all of these policy options have merits, this assessment suggests that minimum energy performance standards will be the most effective, providing results more quickly and with a greater degree of certainty than the other policy options identified above.

For coolrooms, it is unlikely that a physical label will be particularly useful to customers; however there is a case for providing information on best practice design, installation and components for access by customers considering a new installation. This should assist them in specifying efficient coolrooms from the market.

The use of market based incentives to promote increased investment also warrants further investigation, since these will help to reduce the payback period for energy efficiency measures and draw attention to the energy efficiency opportunities.

The impact of industry training is likely to take a long period of time to have a significant impact on energy consumption, however it should be considered alongside general efforts to improve the skill-base in Australia and orientate it towards more energy efficient outcomes.

6.10 Recommendations

Given the significant energy reduction benefits achievable with WICs of 30% which are currently not being realized, we recommend the implementation of minimum energy performance standards. We propose a regulation customised for Australian market and ambient conditions that is harmonised with the US EISA legislation. Any energy efficiency regulation would be additional to pre-existing legislation, requirements or guidelines which cover other aspects of the design, construction or components relating to WICs.

This approach of a dedicated standard would avoid regulating structural components such as insulation, glass and doors through building codes. The key areas encompassed by the standard would be as follows:

Minimum standards on all structural aspects that affect the thermal performance of the WIC and major equipment such as:

- Insulation panels for walls, ceilings and doors to have an R-value of at least 4.5 m^2K/W (equates to 100mm PIR or 200mm EPS) on medium temperature WICs and 6.0 m^2K/W (thicker than 150mm PIR) on low temperature WICs;
- Minimum thermal insulation ratings on floors of at least 4.9 m^2K/W for all WICs;
- Transparent windows and doors to have double glazed on medium temperature WICs and triple glazed on freezers; all glass panes to have heat reflective treatment and gas fill;
- Proper sealing of room, which prescribes the joins of insulation panels, types of doors and door gaskets;
- Energy-efficient lighting with interior lights to use light sources with an efficacy of 40 lumens per watt or more, and lights in doors to have an efficiency equal to or better than LED lights;
- Anti-sweat heater controls that sense humidity and switch off when not required rather operating constantly; and
- Defrost controls to be ‘demand’ or ‘adaptive’ (sometimes referred to as ‘smart’ defrost) controls rather than using a simple timer to initiate defrosting.
- High-efficiency refrigeration compressors, as recommended in Section 3
- Evaporator and condenser fan motors meeting MEPS levels as recommended in Section 4.

6.11 References

ABS 8165.0, 2006	Counts of Australian Businesses, Australian Bureau of Statistics, 2006
AS 1366, Parts 1 to 3-1992	Physical Properties of rigid cellular polystyrene,

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Attachment 4: Energy Independence and Security Act of 2007

Summary of Requirements for Walk-in coolers and Walk-in freezers

Definition:

The terms ‘walk-in cooler’ and ‘walk-in freezer’ mean an enclosed storage space refrigerated to temperatures, respectively, above, and at or below 32 degrees Fahrenheit (0°C) that can be walked into, and has a total chilled storage area of less than 3,000 square feet (279 square meters or 16.7m x 16.7m).

Exclusions:

The terms ‘walk-in cooler’ and ‘walk-in freezer’ do not include products designed and marketed exclusively for medical, scientific, or research purposes.

Each walk-in cooler or walk-in freezer manufactured on or after January 1, 2009, shall:

- Have automatic door closers that firmly close all walk-in doors that have been closed to within 1 inch (25.4 mm) of full closure, except that this subparagraph shall not apply to doors wider than 3 feet 9 inches (1143 mm) or taller than 7 feet (2134 mm);
- Have strip doors, spring hinged doors, or other method of minimizing infiltration when doors are open;
- Contain wall, ceiling, and door insulation of at least R-25 ft^2°F/Btu (R-value of 4.4 m^2K/W in SI units) for coolers and R–32 ft^2°F/Btu (R-value of 5.6 m^2K/W in SI units) for freezers, except that this subparagraph shall not apply to glazed portions of doors nor to structural members[18];
- Contain floor insulation of at least R–28 (R-value of 4.9 m^2K/W in SI units) for freezers;
- Evaporator fan motors of under 1 horsepower and less than 460 volts, use;
- Electronically commutated motors (brushless direct current motors)[19]; or
- Three-phase motors;
- Condenser fan motors of under 1 horsepower, use;
- Electronically commutated motors;
- Permanent split capacitor-type motors; or
- Three-phase motors; and
- All interior lights, use light sources with an efficacy of 40 lumens per watt or more, including ballast losses (if any), except that light sources with an efficacy of 40 lumens per watt or less, including ballast losses (if any), may be used in conjunction with a timer or device that turns off the lights within 15 minutes of when the walk-in cooler or walk-in freezer is not occupied by people.

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[18] The R-value can be expressed in SI units, typically m^2K/W (or equivalently to $m^2°C/W$) or in the United States, R-values are given in units of $ft^2°F/Btu$. The conversion between SI and US units of R-value is 1 $h·ft^2°F/Btu$ = 0.176110 $K·m^2/W$, or 1 $K·m^2/W$ = 5.678263 $h·ft^2·°F/Btu$.

[19] The requirements for electronically commutated motors shall take effect January 1, 2009, unless, prior to that date, the Secretary determines that such motors are only available from 1 manufacturer. The Secretary may allow other types of motors if the Secretary determines that, on average, those other motors use no more energy in evaporator fan applications than electronically commutated motors. The Secretary shall establish the maximum energy consumption level for motors used in evaporator fan applications not later than January 1, 2010.

Each walk-in cooler or walk-in freezer with transparent reach-in doors manufactured on or after January 1, 2009, shall also meet the following specifications:

- Transparent reach-in doors for walk-in freezers and windows in walk-in freezer doors shall be of triple-pane glass with either heat-reflective treated glass or gas fill;
- Transparent reach-in doors for walk-in coolers and windows in walk-in cooler doors shall be;
- Double-pane glass with heat-reflective treated glass and gas fill; or
- Triple-pane glass with either heat-reflective treated glass or gas fill;
- If the appliance has an anti-sweat heater without anti-sweat heat controls, the appliance shall have a total door rail, glass, and frame heater power draw of not more than 7.1 watts per square foot of door opening (for freezers) and 3.0 watts per square foot of door opening (for coolers);
- If the appliance has an anti-sweat heater with anti-sweat heat controls, and the total door rail, glass, and frame heater power draw is more than 7.1 watts per square foot of door opening (for freezers) and 3.0 watts per square foot of door opening (for coolers), the anti-sweat heat controls shall reduce the energy use of the anti-sweat heater in a quantity corresponding to the relative humidity in the air outside the door or to the condensation on the inner glass pane.

Test Methods:

For the purpose of test procedures for walk-in coolers and walk-in freezers:

- The R value shall be the 1/K factor multiplied by the thickness of the panel;
- The K factor shall be based on ASTM test procedure C518–2004;
- For calculating the R value for freezers, the K factor of the foam at 20°F (-6.7°C) (average foam temperature) shall be used;
- For calculating the R value for coolers, the K factor of the foam at 55°F (12.8°C) (average foam temperature) shall be used.

Future Standards:

Not later than January 1, 2012, the Secretary shall publish performance-based standards for walk-in coolers and walk-in freezers that achieve the maximum improvement in energy that the Secretary determines is technologically feasible and economically justified.

The standards shall apply to products described above that are manufactured beginning on the date that is 3 years after the final rule is published.

Not later than January 1, 2010, the Secretary shall establish a test procedure to measure the energy-use of walk-in coolers and walk-in freezers. The test procedure may be based on computer modelling, if the computer model or models have been verified using the results of laboratory tests on a significant sample of walk-in coolers and walk-in freezers.

Labelling

Section 344(e) of the Energy Policy and Conservation Act (42 U.S.C. 6315(e)) is amended by inserting ‘‘walk-in coolers and walk-in freezers,’’ after ‘‘commercial clothes washers,’’ each place it appears.

Attachment 5: Refrigeration load calculations

A series of refrigeration load calculations were performed using Heatcraft heat-load software for variations outlined in Table 41. The summary results from each calculation are provided on the pages that follow.

Table 41: Series of calculations undertaken

Heat-load calculation	Dimensions w x l x height (m)	Usage (Medium/ high)	Door type (Solid/glass/ double glazed)	Insulation	
				Reference	Improved
1. a)	**1.8 x 1.8 x 2.4**	Medium	Solid	75mmEPS	100mmEPS
1. b)		High	Solid	75mmEPS	100mmPIR
1. c)		High	Glass	75mmEPS	100mmPIR
1 d)		High	Double glazed	75mmEPS	100mmPIR
2.	**3 x 3 x 2.4**	Medium	Solid	75mmEPS	100mmPIR
3.	**6 x 4 x 3**	Medium	Solid	75mmEPS	100mmPIR
4.	**6 x 6 x 4**	Medium	Solid	75mmEPS	100mmPIR
5.	**10 x 10 x 4**	Medium	Solid	75mmEPS	100mmPIR

Heat-load calculation (75mm EPS)

Room Data

Room Type Coolroom

Room Usage Medium Room Temp 5 C Amb 35 C 50 %RH 24 Hours Run

Room Dimensions Length 1800 Width 1800 Height 2400

Room Construction	Panel	Thickness	Insulation	Ext Temp
	Side 1	75	Polystyrene	35
	Side 2	75	Polystyrene	35
	Side 3	75	Polystyrene	35
	Side 4	75	Polystyrene	35
	Ceiling	75	Polystyrene	35
				Temp Diff
	Floor	100	Concrete	1

Glass Doors Qty 0 Width N/A Height N/A Glazing N/A

Miscellaneous Load Data

Lighting Qty 0 40 Watt each 10 Hours

Occupancy Qty 0 People 2 Hours

Other Loads 0 Watt total 24 Hours

Material Handling None 0 Kg 2 Hours

Evaporator Motors Qty 0 50 Watt each 24 Hours

Product Data

Product N/A N/A kg

Entering Temp N/A C Leaving Temp N/A C Pull-down N/A Hours

Freeze Temp N/A C Sp Heat < Freezing N/A kJ/kg Sp Heat > Freezing N/A kJ/kg

Calculated Loads

Product Load (W)		**Room Load (W)**		**Misc. Load (W)**	
Above Freezing	N/A	Transmission	316	Lights	0
Below Freezing	N/A	Air Change	254	Occupancy	0
Latent Heat	N/A	Glass Doors	0	Other	0
Heat of Respiration	N/A	Floor	38	Matl. Handling	0
				Evap. Motors	0

Total Heat-load: 608 W + 10% Safety Margin = 668W

Refrigeration Capacity Required: 668 W @ 24Hrs run

Heat-load calculation (100mm PIR)

Room Data

Room Type Coolroom

Room Usage Medium Room Temp 5 C Amb 35 C 50 %RH 24 Hours Run

Room Dimensions Length 1800 Width 1800 Height 2400

Room Construction	Panel	Thickness	Insulation	Ext Temp
	Side 1	100	Polyiscyanurate	35
	Side 2	100	Polyiscyanurate	35
	Side 3	100	Polyiscyanurate	35
	Side 4	100	Polyiscyanurate	35
	Ceiling	100	Polyiscyanurate	35
				Temp Diff
	Floor	100	Concrete	1

Glass Doors Qty 0 Width N/A Height N/A Glazing N/A

Miscellaneous Load Data

Lighting Qty 0 40 Watt each 10 Hours

Occupancy Qty 0 People 2 Hours

Other Loads 0 Watt total 24 Hours

Material Handling None 0 Kg 2 Hours

Evaporator Motors Qty 0 50 Watt each 24 Hours

Product Data

Product N/A N/A kg

Entering Temp N/A C Leaving Temp N/A C Pulldown N/A Hours

Freeze Temp N/A C Sp Heat < Freezing N/A kJ/kg Sp Heat > Freezing N/A kJ/kg

Calculated Loads

Product Load (W)		Room Load (W)		Misc. Load (W)	
Above Freezing	N/A	Transmission	129	Lights	0
Below Freezing	N/A	Air Change	244	Occupancy	0
Latent Heat	N/A	Glass Doors	0	Other	0
Heat of Respiration	N/A	Floor	38	Matl. Handling	0
				Evap. Motors	0

Total Heat-load: 411 W + 10% Safety Margin = 452W

Refrigeration Capacity Required: 452 W @ 24Hrs run

Heat-load calculation (75mm EPS, high usage)

Room Data

Room Type Coolroom

Room Usage Heavy Room Temp 5 C Amb 35 C 50 %RH 24 Hours Run

Room Dimensions Length 1800 Width 1800 Height 2400

Room Construction	Panel	Thickness	Insulation	Ext Temp
	Side 1	75	Polystyrene	35
	Side 2	75	Polystyrene	35
	Side 3	75	Polystyrene	35
	Side 4	75	Polystyrene	35
	Ceiling	75	Polystyrene	35
				Temp Diff
	Floor	100	Concrete	1

Glass Doors Qty 0 Width N/A Height N/A Glazing N/A

Miscellaneous Load Data

Lighting Qty 0 40 Watt each 10 Hours

Occupancy Qty 0 People 2 Hours

Other Loads 0 Watt total 24 Hours

Material Handling None 0 Kg 2 Hours

Evaporator Motors Qty 0 50 Watt each 24 Hours

Product Data

Product N/A N/A kg

Entering Temp N/A C Leaving Temp N/A C Pull-down N/A Hours

Freeze Temp N/A C Sp Heat < Freezing N/A kJ/kg Sp Heat > Freezing N/A kJ/kg

Calculated Loads

Product Load (W)		**Room Load (W)**		**Misc. Load (W)**	
Above Freezing	N/A	Transmission	316	Lights	0
Below Freezing	N/A	Air Change	508	Occupancy	0
Latent Heat	N/A	Glass Doors	0	Other	0
Heat of Respiration	N/A	Floor	38	Matl. Handling	0
				Evap. Motors	0

Total Heat-load: 862 W + 10% Safety Margin = 948W

Refrigeration Capacity Required: 948 W @ 24Hrs run

Heat-load calculation (100mm PIR, high usage)

Room Data

Room Type   Coolroom

Room Usage Heavy   Room Temp   5 C   Amb 35 C   50 %RH   24 Hours Run

Room Dimensions Length 1800   Width 1800   Height 2400

Room Construction	Panel	Thickness	Insulation	Ext Temp
	Side 1	100	Polyiscyanurate	35
	Side 2	100	Polyiscyanurate	35
	Side 3	100	Polyiscyanurate	35
	Side 4	100	Polyiscyanurate	35
	Ceiling	100	Polyiscyanurate	35
				Temp Diff
	Floor	100	Concrete	1

Glass Doors Qty 0   Width N/A   Height N/A   Glazing N/A

Miscellaneous Load Data

Lighting   Qty 0   40 Watt each   10 Hours

Occupancy   Qty 0 People   2 Hours

Other Loads   0 Watt total   24 Hours

Material Handling   None   0 Kg 2 Hours

Evaporator Motors Qty 0   50 Watt each 24 Hours

Product Data

Product   N/A   N/A kg

Entering Temp   N/A C   Leaving Temp N/A C   Pull-down N/A Hours

Freeze Temp   N/A C   Sp Heat < Freezing N/A kJ/kg   Sp Heat > Freezing N/A kJ/kg

Calculated Loads

Product Load (W)		**Room Load (W)**		**Misc. Load (W)**	
Above Freezing	N/A	Transmission	129	Lights	0
Below Freezing	N/A	Air Change	489	Occupancy	0
Latent Heat	N/A	Glass Doors	0	Other	0
Heat of Respiration	N/A	Floor	38	Matl. Handling	0
				Evap. Motors	0

Total Heat-load: 656 W + 10% Safety Margin = 721W

Refrigeration Capacity Required: 721 W @ 24Hrs run

Heat-load calculation (75mm EPS, high usage, glass)

Room Data

Room Type Coolroom

Room Usage Heavy Room Temp 5 C Amb 35 C 50 %RH 24 Hours Run

Room Dimensions Length 1800 Width 1800 Height 2400

Room Construction	Panel	Thickness	Insulation	Ext Temp
	Side 1	75	Polystyrene	35
	Side 2	75	Polystyrene	35
	Side 3	75	Polystyrene	35
	Side 4	75	Polystyrene	35
	Ceiling	75	Polystyrene	35
				Temp Diff
	Floor	100	Concrete	1

Glass Doors Qty 1 Width 1800 Height 2400 Glazing Single

Miscellaneous Load Data

Lighting Qty 0 40 Watt each 10 Hours

Occupancy Qty 0 People 2 Hours

Other Loads 0 Watt total 24 Hours

Material Handling None 0 Kg 2 Hours

Evaporator Motors Qty 0 50 Watt each 24 Hours

Product Data

Product N/A N/A kg

Entering Temp N/A C Leaving Temp N/A C Pull-down N/A Hours

Freeze Temp N/A C Sp Heat < Freezing N/A kJ/kg Sp Heat > Freezing N/A kJ/kg

Calculated Loads

Product Load (W)		**Room Load (W)**		**Misc. Load (W)**	
Above Freezing	N/A	Transmission	249	Lights	0
Below Freezing	N/A	Air Change	508	Occupancy	0
Latent Heat	N/A	Glass Doors	826	Other	0
Heat of Respiration	N/A	Floor	38	Matl. Handling	0
				Evap. Motors	0

Total Heat-load: 1621 W + 10% Safety Margin = 1783W

Refrigeration Capacity Required: 1783 W @ 24Hrs run

Heat-load calculation (100mm PIR, high usage, glass)

Room Data

Room Type Coolroom

Room Usage Heavy Room Temp 5 C Amb 35 C 50 %RH 24 Hours Run

Room Dimensions Length 1800 Width 1800 Height 2400

Room Construction	Panel	Thickness	Insulation	Ext Temp
	Side 1	100	Polyiscyanurate	35
	Side 2	100	Polyiscyanurate	35
	Side 3	100	Polyiscyanurate	35
	Side 4	100	Polyiscyanurate	35
	Ceiling	100	Polyiscyanurate	35
				Temp Diff
	Floor	100	Concrete	1

Glass Doors Qty 1 Width 1800 Height 2400 Glazing Single

Miscellaneous Load Data

Lighting Qty 0 40 Watt each 10 Hours

Occupancy Qty 0 People 2 Hours

Other Loads 0 Watt total 24 Hours

Material Handling None 0 Kg 2 Hours

Evaporator Motors Qty 0 50 Watt each 24 Hours

Product Data

Product N/A N/A kg

Entering Temp N/A C Leaving Temp N/A C Pull-down N/A Hours

Freeze Temp N/A C Sp Heat < Freezing N/A kJ/kg Sp Heat > Freezing N/A kJ/kg

Calculated Loads

Product Load (W)		**Room Load (W)**		**Misc. Load (W)**	
Above Freezing	N/A	Transmission	102	Lights	0
Below Freezing	N/A	Air Change	489	Occupancy	0
Latent Heat	N/A	Glass Doors	826	Other	0
Heat of Respiration	N/A	Floor	38	Matl. Handling	0
				Evap. Motors	0

Total Heat-load: 1455 W + 10% Safety Margin = 1600W

Refrigeration Capacity Required: 1600 W @ 24Hrs run

Heat-load calculation (75mm EPS, high usage, double glazed glass)

Room Data

Room Type Coolroom

Room Usage Heavy Room Temp 5 C Amb 35 C 50 %RH 24 Hours Run

Room Dimensions Length 1800 Width 1800 Height 2400

Room Construction	Panel	Thickness	Insulation	Ext Temp
	Side 1	75	Polystyrene	35
	Side 2	75	Polystyrene	35
	Side 3	75	Polystyrene	35
	Side 4	75	Polystyrene	35
	Ceiling	75	Polystyrene	35
				Temp Diff
	Floor	100	Concrete	1

Glass Doors Qty 1 Width 1800 Height 2400 Glazing Double

Miscellaneous Load Data

Lighting Qty 0 40 Watt each 10 Hours

Occupancy Qty 0 People 2 Hours

Other Loads 0 Watt total 24 Hours

Material Handling None 0 Kg 2 Hours

Evaporator Motors Qty 0 50 Watt each 24 Hours

Product Data

Product N/A N/A kg

Entering Temp N/A C Leaving Temp N/A C Pull-down N/A Hours

Freeze Temp N/A C Sp Heat < Freezing N/A kJ/kg Sp Heat > Freezing N/A kJ/kg

Calculated Loads

Product Load (W)		**Room Load (W)**		**Misc. Load (W)**	
Above Freezing	N/A	Transmission	249	Lights	0
Below Freezing	N/A	Air Change	508	Occupancy	0
Latent Heat	N/A	Glass Doors	347	Other	0
Heat of Respiration	N/A	Floor	38	Matl. Handling	0
				Evap. Motors	0

Total Heat-load: 1142 W + 10% Safety Margin = 1256W

Refrigeration Capacity Required: 1256 W @ 24Hrs run

Heat-load calculation (100mm PIR, high usage, double glazed glass)

Room Data

Room Type Coolroom

Room Usage Heavy Room Temp 5 C Amb 35 C 50 %RH 24 Hours Run

Room Dimensions Length 1800 Width 1800 Height 2400

Room Construction

Panel	Thickness	Insulation	Ext Temp
Side 1	100	Polyiscyanurate	35
Side 2	100	Polyiscyanurate	35
Side 3	100	Polyiscyanurate	35
Side 4	100	Polyiscyanurate	35
Ceiling	100	Polyiscyanurate	35
			Temp Diff
Floor	100	Concrete	1

Glass Doors Qty 1 Width 1800 Height 2400 Glazing Double

Miscellaneous Load Data

Lighting Qty 0 40 Watt each 10 Hours

Occupancy Qty 0 People 2 Hours

Other Loads 0 Watt total 24 Hours

Material Handling None 0 Kg 2 Hours

Evaporator Motors Qty 0 50 Watt each 24 Hours

Product Data

Product N/A N/A kg

Entering Temp N/A C Leaving Temp N/A C Pull-down N/A Hours

Freeze Temp N/A C Sp Heat < Freezing N/A kJ/kg Sp Heat > Freezing N/A kJ/kg

Calculated Loads

Product Load (W)		**Room Load (W)**		**Misc. Load (W)**	
Above Freezing	N/A	Transmission	102	Lights	0
Below Freezing	N/A	Air Change	489	Occupancy	0
Latent Heat	N/A	Glass Doors	347	Other	0
Heat of Respiration	N/A	Floor	38	Matl. Handling	0
				Evap. Motors	0

Total Heat-load: 976 W + 10% Safety Margin = 1073W

Refrigeration Capacity Required: 1073 W @ 24Hrs run

Heat-load calculation (75mm EPS)

Room Data

Room Type Coolroom

Room Usage Medium Room Temp 5 C Amb 35 C 50 %RH 24 Hours Run

Room Dimensions Length 3000 Width 3000 Height 2400

Room Construction	Panel	Thickness	Insulation	Ext Temp
	Side 1	75	Polystyrene	35
	Side 2	75	Polystyrene	35
	Side 3	75	Polystyrene	35
	Side 4	75	Polystyrene	35
	Ceiling	75	Polystyrene	35
				Temp Diff
	Floor	100	Concrete	1

Glass Doors Qty 0 Width N/A Height N/A Glazing N/A

Miscellaneous Load Data

Lighting Qty 0 40 Watt each 10 Hours

Occupancy Qty 0 People 2 Hours

Other Loads 0 Watt total 24 Hours

Material Handling None 0 Kg 2 Hours

Evaporator Motors Qty 0 50 Watt each 24 Hours

Product Data

Product N/A N/A kg

Entering Temp N/A C Leaving Temp N/A C Pull-down N/A Hours

Freeze Temp N/A C Sp Heat < Freezing N/A kJ/kg Sp Heat > Freezing N/A kJ/kg

Calculated Loads

Product Load (W)		Room Load (W)		Misc. Load (W)	
Above Freezing	N/A	Transmission	582	Lights	0
Below Freezing	N/A	Air Change	413	Occupancy	0
Latent Heat	N/A	Glass Doors	0	Other	0
Heat of Respiration	N/A	Floor	106	Matl. Handling	0
				Evap. Motors	0

Total Heat-load: 1101 W + 10% Safety Margin = 1211W

Refrigeration Capacity Required: 1211 W @ 24Hrs run

Heat-load calculation (100mm PIR)

Room Data

Room Type Coolroom

Room Usage Medium Room Temp 5 C Amb 35 C 50 %RH 24 Hours Run

Room Dimensions Length 3000 Width 3000 Height 2400

Room Construction	Panel	Thickness	Insulation	Ext Temp
	Side 1	100	Polyiscyanurate	35
	Side 2	100	Polyiscyanurate	35
	Side 3	100	Polyiscyanurate	35
	Side 4	100	Polyiscyanurate	35
	Ceiling	100	Polyiscyanurate	35
				Temp Diff
	Floor	100	Concrete	1

Glass Doors Qty 0 Width N/A Height N/A Glazing N/A

Miscellaneous Load Data

Lighting Qty 0 40 Watt each 10 Hours

Occupancy Qty 0 People 2 Hours

Other Loads 0 Watt total 24 Hours

Material Handling None 0 Kg 2 Hours

Evaporator Motors Qty 0 50 Watt each 24 Hours

Product Data

Product N/A N/A kg

Entering Temp N/A C Leaving Temp N/A C Pull-down N/A Hours

Freeze Temp N/A C Sp Heat < Freezing N/A kJ/kg Sp Heat > Freezing N/A kJ/kg

Calculated Loads

Product Load (W)		**Room Load (W)**		**Misc. Load (W)**	
Above Freezing	N/A	Transmission	238	Lights	0
Below Freezing	N/A	Air Change	405	Occupancy	0
Latent Heat	N/A	Glass Doors	0	Other	0
Heat of Respiration	N/A	Floor	106	Matl. Handling	0
				Evap. Motors	0

Total Heat-load: 749 W + 10% Safety Margin = 823W

Refrigeration Capacity Required: 823 W @ 24Hrs run

Heat-load calculation (75mm EPS)

Room Data

Room Type Coolroom

Room Usage Medium Room Temp 5 C Amb 35 C 50 %RH 24 Hours Run

Room Dimensions Length 6000 Width 4000 Height 3000

Room Construction	Panel	Thickness	Insulation	Ext Temp
	Side 1	75	Polystyrene	35
	Side 2	75	Polystyrene	35
	Side 3	75	Polystyrene	35
	Side 4	75	Polystyrene	35
	Ceiling	75	Polystyrene	35
				Temp Diff
	Floor	100	Concrete	1

Glass Doors Qty 0 Width N/A Height N/A Glazing N/A

Miscellaneous Load Data

Lighting Qty 0 40 Watt each 10 Hours

Occupancy Qty 0 People 2 Hours

Other Loads 0 Watt total 24 Hours

Material Handling None 0 Kg 2 Hours

Evaporator Motors Qty 0 50 Watt each 24 Hours

Product Data

Product N/A N/A kg

Entering Temp N/A C Leaving Temp N/A C Pull-down N/A Hours

Freeze Temp N/A C Sp Heat < Freezing N/A kJ/kg Sp Heat > Freezing N/A kJ/kg

Calculated Loads

Product Load (W)		**Room Load (W)**		**Misc. Load (W)**	
Above Freezing	N/A	Transmission	1293	Lights	0
Below Freezing	N/A	Air Change	719	Occupancy	0
Latent Heat	N/A	Glass Doors	0	Other	0
Heat of Respiration	N/A	Floor	285	Matl. Handling	0
				Evap. Motors	0

Total Heat-load: 2297 W + 10% Safety Margin = 2526W

Refrigeration Capacity Required: 2526 W @ 24Hrs run

Heat-load calculation (100mm PIR)

Room Data

Room Type Coolroom

Room Usage Medium Room Temp 5 C Amb 35 C 50 %RH 24 Hours Run

Room Dimensions Length 6000 Width 4000 Height 3000

Room Construction	Panel	Thickness	Insulation	Ext Temp
	Side 1	100	Polyiscyanurate	35
	Side 2	100	Polyiscyanurate	35
	Side 3	100	Polyiscyanurate	35
	Side 4	100	Polyiscyanurate	35
	Ceiling	100	Polyiscyanurate	35
				Temp Diff
	Floor	100	Concrete	1

Glass Doors Qty 0 Width N/A Height N/A Glazing N/A

Miscellaneous Load Data

Lighting Qty 0 40 Watt each 10 Hours

Occupancy Qty 0 People 2 Hours

Other Loads 0 Watt total 24 Hours

Material Handling None 0 Kg 2 Hours

Evaporator Motors Qty 0 50 Watt each 24 Hours

Product Data

Product N/A N/A kg

Entering Temp N/A C Leaving Temp N/A C Pull-down N/A Hours

Freeze Temp N/A C Sp Heat < Freezing N/A kJ/kg Sp Heat > Freezing N/A kJ/kg

Calculated Loads

Product Load (W)		**Room Load (W)**		**Misc. Load (W)**	
Above Freezing	N/A	Transmission	529	Lights	0
Below Freezing	N/A	Air Change	708	Occupancy	0
Latent Heat	N/A	Glass Doors	0	Other	0
Heat of Respiration	N/A	Floor	285	Matl. Handling	0
				Evap. Motors	0

Total Heat-load: 1522 W + 10% Safety Margin = 1674W

Refrigeration Capacity Required: 1674 W @ 24Hrs run

Heat-load calculation (75mm EPS)

Room Data

Room Type Coolroom

Room Usage Medium Room Temp 5 C Amb 35 C 50 %RH 24 Hours Run

Room Dimensions Length 6000 Width 6000 Height 4000

Room Construction	Panel	Thickness	Insulation	Ext Temp
	Side 1	75	Polystyrene	35
	Side 2	75	Polystyrene	35
	Side 3	75	Polystyrene	35
	Side 4	75	Polystyrene	35
	Ceiling	75	Polystyrene	35
				Temp Diff
	Floor	100	Concrete	1

Glass Doors Qty 0 Width N/A Height N/A Glazing N/A

Miscellaneous Load Data

Lighting Qty 0 40 Watt each 10 Hours

Occupancy Qty 0 People 2 Hours

Other Loads 0 Watt total 24 Hours

Material Handling None 0 Kg 2 Hours

Evaporator Motors Qty 0 50 Watt each 24 Hours

Product Data

Product N/A N/A kg

Entering Temp N/A C Leaving Temp N/A C Pull-down N/A Hours

Freeze Temp N/A C Sp Heat < Freezing N/A kJ/kg Sp Heat > Freezing N/A kJ/kg

Calculated Loads

Product Load (W)		**Room Load (W)**		**Misc. Load (W)**	
Above Freezing	N/A	Transmission	2032	Lights	0
Below Freezing	N/A	Air Change	986	Occupancy	0
Latent Heat	N/A	Glass Doors	0	Other	0
Heat of Respiration	N/A	Floor	427	Matl. Handling	0
				Evap. Motors	0

Total Heat-load: 3445 W + 10% Safety Margin = 3789W

Refrigeration Capacity Required: 3789 W @ 24Hrs run

Heat-load calculation (100mm PIR)

Room Data

Room Type Coolroom

Room Usage Medium Room Temp 5 C Amb 35 C 50 %RH 24 Hours Run

Room Dimensions Length 6000 Width 6000 Height 4000

Room Construction

Panel	Thickness	Insulation	Ext Temp
Side 1	100	Polyiscyanurate	35
Side 2	100	Polyiscyanurate	35
Side 3	100	Polyiscyanurate	35
Side 4	100	Polyiscyanurate	35
Ceiling	100	Polyiscyanurate	35
			Temp Diff
Floor	100	Concrete	1

Glass Doors Qty 0 Width N/A Height N/A Glazing N/A

Miscellaneous Load Data

Lighting Qty 0 40 Watt each 10 Hours

Occupancy Qty 0 People 2 Hours

Other Loads 0 Watt total 24 Hours

Material Handling None 0 Kg 2 Hours

Evaporator Motors Qty 0 50 Watt each 24 Hours

Product Data

Product N/A N/A kg

Entering Temp N/A C Leaving Temp N/A C Pull-down N/A Hours

Freeze Temp N/A C Sp Heat < Freezing N/A kJ/kg Sp Heat > Freezing N/A kJ/kg

Calculated Loads

Product Load (W)		**Room Load (W)**		**Misc. Load (W)**	
Above Freezing	N/A	Transmission	831	Lights	0
Below Freezing	N/A	Air Change	979	Occupancy	0
Latent Heat	N/A	Glass Doors	0	Other	0
Heat of Respiration	N/A	Floor	427	Matl. Handling	0
				Evap. Motors	0

Total Heat-load: 2237 W + 10% Safety Margin = 2460W

Refrigeration Capacity Required: 2460 W @ 24Hrs run

Heat-load calculation (75mm EPS)

Room Data

Room Type Coolroom

Room Usage Medium Room Temp 5 C Amb 35 C 50 %RH 24 Hours Run

Room Dimensions Length 10000 Width 10000 Height 4000

Room Construction	Panel	Thickness	Insulation	Ext Temp
	Side 1	75	Polystyrene	35
	Side 2	75	Polystyrene	35
	Side 3	75	Polystyrene	35
	Side 4	75	Polystyrene	35
	Ceiling	75	Polystyrene	35
				Temp Diff
	Floor	100	Concrete	1

Glass Doors Qty 0 Width N/A Height N/A Glazing N/A

Miscellaneous Load Data

Lighting Qty 0 40 Watt each 10 Hours

Occupancy Qty 0 People 2 Hours

Other Loads 0 Watt total 24 Hours

Material Handling None 0 Kg 2 Hours

Evaporator Motors Qty 0 50 Watt each 24 Hours

Product Data

Product N/A N/A kg

Entering Temp N/A C Leaving Temp N/A C Pull-down N/A Hours

Freeze Temp N/A C Sp Heat < Freezing N/A kJ/kg Sp Heat > Freezing N/A kJ/kg

Calculated Loads

Product Load (W)		**Room Load (W)**		**Misc. Load (W)**	
Above Freezing	N/A	Transmission	4003	Lights	0
Below Freezing	N/A	Air Change	1550	Occupancy	0
Latent Heat	N/A	Glass Doors	0	Other	0
Heat of Respiration	N/A	Floor	1187	Matl. Handling	0
				Evap. Motors	0

Total Heat-load: 6740 W + 10% Safety Margin = 7414W

Refrigeration Capacity Required: 7414 W @ 24Hrs run

Heat-load calculation (100mm PIR)

Room Data

Room Type Coolroom

Room Usage Medium Room Temp 5 C Amb 35 C 50 %RH 24 Hours Run

Room Dimensions Length 10000 Width 10000 Height 4000

Room Construction	Panel	Thickness	Insulation	Ext Temp
	Side 1	100	Polyiscyanurate	35
	Side 2	100	Polyiscyanurate	35
	Side 3	100	Polyiscyanurate	35
	Side 4	100	Polyiscyanurate	35
	Ceiling	100	Polyiscyanurate	35
				Temp Diff
	Floor	100	Concrete	1

Glass Doors Qty 0 Width N/A Height N/A Glazing N/A

Miscellaneous Load Data

Lighting Qty 0 40 Watt each 10 Hours

Occupancy Qty 0 People 2 Hours

Other Loads 0 Watt total 24 Hours

Material Handling None 0 Kg 2 Hours

Evaporator Motors Qty 0 50 Watt each 24 Hours

Product Data

Product N/A N/A kg

Entering Temp N/A C Leaving Temp N/A C Pull-down N/A Hours

Freeze Temp N/A C Sp Heat < Freezing N/A kJ/kg Sp Heat > Freezing N/A kJ/kg

Calculated Loads

Product Load (W)		**Room Load (W)**		**Misc. Load (W)**	
Above Freezing	N/A	Transmission	1637	Lights	0
Below Freezing	N/A	Air Change	1539	Occupancy	0
Latent Heat	N/A	Glass Doors	0	Other	0
Heat of Respiration	N/A	Floor	1187	Matl. Handling	0
				Evap. Motors	0

Total Heat-load: 4363 W + 10% Safety Margin = 4799W

Refrigeration Capacity Required: 4799 W @ 24Hrs run

7 Process & Cold Storage Refrigeration

7.1 Introduction

Process refrigeration (PR) is a term commonly used to describe refrigeration applications in manufacturing processes and those using a heat exchanger and secondary refrigerant such as water, brine or glycol[20] to create the refrigerating effect. This refrigerating effect can be achieved with refrigeration systems that use anhydrous Ammonia as the primary refrigerant or from packaged liquid chillers. Refrigeration systems that use anhydrous Ammonia are commonly described by the HVAC&R industry as Industrial Refrigeration (IR) systems[21]. This study reviews Cold Storage (CS) refrigeration and PR together since the large majority of cold storage warehouses are serviced with large IR systems.

PR and CS consume at least 4,120 GWh of electricity per annum, which is equivalent to approximately 31% of total electricity used in Australia for non domestic refrigeration. Packaged liquid chillers account for the largest portion consuming 2,860 GWh of electricity per annum with IR equipment consuming 630 GWh per annum in CS facilities and a similar amount in process refrigeration applications.

Figure 88 outlines the common industry terminology, applications and systems in this sector. It should be noted that only refrigerating devices that use the *vapour compression cycle* are included in this study. Refrigerating devices and chillers that use other refrigeration cycles such as *absorption*, *adsorption* and *rankine* are rare and are excluded from this study as they typically use different equipment, components and refrigerants.

Milk Vat chillers and beverage coolers are not covered in this section, as they are application specific liquid chillers designed and serviced by industry specialists rather than mainstream packaged liquid chiller suppliers. These chillers are covered in Sections 8 and 9 respectively, in order to provide more detail about the intricacies of the equipment, markets and energy saving opportunities.

This section describes PR and CS applications, outlining the main types of equipment, systems and accessories in common use. A market profile is provided for process applications in industry, packaged liquid chillers and CS facilities with estimates of electricity consumption and greenhouse gas emissions attributable to refrigeration equipment in these sectors.

Significant energy reduction opportunities can be achieved from optimising the performance of large energy-intensive systems where energy consumption is determined by system configuration and operation as well as efficient components. This section also reviews overseas experience with performance measurement, monitoring and benchmarking, which builds a case for Australia to introduce a web based online benchmarking system for the CS industry.

[20] Brine is water with dissolved salt (usually sodium chloride) with salinity levels greater than 50 parts per thousand. The addition of salt to water lowers the freezing temperature of the solution and improves heat transport. Ethylene glycol, commonly referred to as glycol has a lower freezing point than water with the benefit of corrosion protection properties, inhibited propylene glycol is non-toxic and is usually used in food applications. Inhibited ethylene glycol is also used (Bohn, 2007).

[21] Industrial refrigeration systems use anhydrous Ammonia meaning it does not contain water, the chemical symbol is NH_3 and the ASHRAE refrigerant number is R717 (AIRAH, 2003).

Figure 88: Process and cold storage refrigeration terminology and application map

<table>
<tr><td>Non domestic refrigeration as defined in this study</td><td colspan="6">Refrigerating systems with an application temperature range below 7oC using the Vapour Compression cycle with reciprocating, scroll, rotary, screw and centrifugal compressors driven by electric motors</td></tr>
<tr><td>Applications</td><td>Primary industry and processing in refrigerated Food Chain</td><td colspan="2">Manufacturing, process and construction industries</td><td colspan="3">Cold storage warehouses</td></tr>
<tr><td>Common industry terminology</td><td colspan="2">Packaged liquid chillers</td><td colspan="3">Industrial refrigeration</td><td>Commercial refrigeration</td></tr>
<tr><td>Refrigerant type</td><td colspan="2">Fluorocarbons</td><td colspan="3">Ammonia</td><td>Fluorocarbons</td></tr>
<tr><td rowspan="2">System types and refrigerating effect</td><td colspan="4">Process refrigeration chillers</td><td colspan="2">Direct expansion systems</td></tr>
<tr><td colspan="4">Heat exchanger and secondary fluid to create refrigeration effect or provide chilled water for a manufacturing process</td><td colspan="2">Air-cooled evaporator</td></tr>
</table>

7.2 Process and cold storage applications

7.2.1 Process refrigeration applications

Process refrigeration applications using Industrial Refrigeration (IR) equipment generally involve large chilling, freezing and ice making systems in the primary and secondary stages of the Cold Food Chain. The main industry applications in Australia are:

- Meat abattoirs and poultry facilities;
- Seafood chilling, freezing and processing;
- Dairy and ice cream plants;
- Wineries and breweries;
- Bakery industry for chilling and freezing to retard tempering of dough prior to batch cooking;
- Fruit juice, vegetable juice, and soft drink processing facilities;
- Fruit and vegetable industry for process cooling;
- Water chilling for food processes and as an additive;
- Ice making for manufacturing and storage[22];
- Confectionary to temper chocolate and in cooling tunnels; and
- Mines and petro-chemical plants.

[22] These are large ice making facilities not covered by the recent MEPS review on ice makers and ice storage bins that are widely used in hospitality and catering service industries.

Packaged liquid chillers are used in processing, manufacturing and research applications in a variety of industry sectors including the Cold Food Chain to service similar applications to IR except for severe freezing applications. Examples of packaged liquid chillers used in other industry sectors in Australia are:

- Plastics and rubber manufacturing used to chill water to dissipate heat in dies and moulds or regulate temperatures in extrusion machinery, which allows greater control and product uniformity;
- Pharmaceutical plants where water chillers are used to dissipate heat from jacketed vats of creams, emollients and healthcare products before packaging;
- Institutional research facilities in Universities, CSIRO and CSL use liquid chillers in a diverse range of research and development applications;
- Corporate laboratories undertaking product and process development in the mining, mineral processing, chemical, petroleum, pharmaceutical and medical research industry sectors;
- Mechanical engineering cooling applications associated with machine tools, welding machines, rolling mills, presses, cutting, profiling, polishing, electric spark machinery, hydraulic oil cooling of large machinery and cooling large drives and crushers in the mining industry;
- Titanium water chillers for major public aquariums, marine research laboratories and industry applications where corrosive fluids need to be cooled;
- Refrigerated air-dryers for compressed air used in manufacturing, mining and industrial sectors, however these chillers are sometimes classed as air conditioning chillers; and
- Diverse range of process chilling applications including chemical processes with solvents and paints; polyurethane foam mixers; printing processes; cold water for concrete batch plants, desalination plants, industrial cleaning and timber processes.

7.2.2 Cold Storage applications

The principal purpose of cold storage facilities is to provide public or private temperature controlled warehousing for chilled and frozen foods in the Cold Food Chain. The size of these facilities range from warehouses as small as 2,800 m^3 (400 m^2, 7 m high) to large distribution facilities over 200,000 m^3. It should be noted that these are considerably larger than walk-in coolrooms covered in Section 6, which typically are less than 280 m^2.

The large majority of cold storage warehouses are serviced with large IR systems that use ammonia as a refrigerant. These facilities include traditional forklift operated stores and automated high-rise facilities up to 9 pallets high catering for retail distribution or purpose built facilities interconnected with food processing facilities. Figure 89 provides an illustration of a typical cold storage facility.

Figure 89: Multiple evaporators cool a large Cold Storage facility

(Source: Lu-ve Contardo)

7.2.3 Refrigeration capacities and applications

Process refrigeration applications using packaged liquid chillers range from small 1kWr air-cooled units used in laboratories to 1,000 kWr machines for liquid chilling in food and industrial processes.

IR systems are used virtually exclusively in large process refrigeration applications greater than 1,000kWr and all new cold storage facilities, sometimes in combination with secondary refrigerants. IR systems start to become commercially viable (compared to refrigeration equipment operating on fluorocarbons) at sizes above approximately 100kWr for low temperature applications, and above 300kWr for medium temperature applications. IR systems can range in capacity up to 9,000kWr or more in beverage processing applications such as wineries where grapes enter large jacketed tanks from harvest at 20°C to 30°C and need to be cooled to close to 0°C rapidly to manage the fermentation process.

Cold storage facilities can range from small warehouses with refrigeration capacities around 200kWr to 2,000 kWr in large distribution centres[23]. Very large IR applications up to 30,000kWr can be found in mining operations to provide air conditioning, and are therefore outside the scope of this study.

Figure 90 provides a diagram summarising the applications described in this section by typical capacities of refrigeration equipment.

Figure 90: Typical refrigeration capacities for process refrigeration and cold storage applications in Australia

<table>
<tr><th>Application size</th><th>Cooling capacity (kWr)</th><th colspan="3">Process Refrigeration</th><th>Cold storage</th></tr>
<tr><td>Extra large</td><td>≥1055</td><td>n.a.</td><td>n.a.</td><td rowspan="3">Food Chain chilling, freezing and ice making</td><td rowspan="3">Food Chain cold storage</td></tr>
<tr><td>Large</td><td>≥528 to <1055</td><td rowspan="3">Food Chain liquid chilling</td><td rowspan="3">Other Industry liquid chilling</td></tr>
<tr><td>Medium</td><td>≥110 to <528</td></tr>
<tr><td>Small</td><td>≥10 to <110</td><td>n.a.</td><td>n.a.</td></tr>
<tr><td colspan="2">Equipment type</td><td colspan="2">Packaged liquid chillers</td><td colspan="2">Industrial refrigeration systems</td></tr>
</table>

[23] A 'rules of thumb' for Cold Storage design is 100 W per m^2 with heights of 12m versus 250 to 300 kWr per m^2 on walk in cool rooms with heights of 3 to 4m.

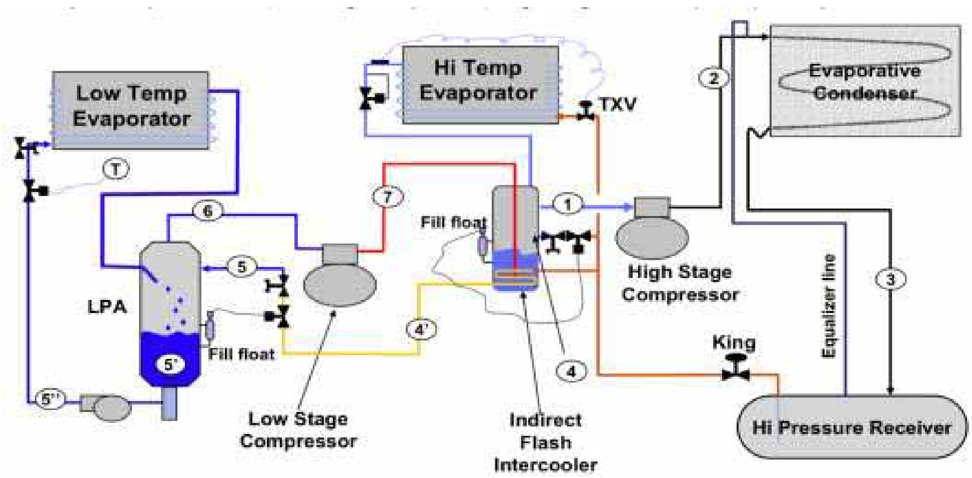
7.3 Description of technology

7.3.1 Types of industrial refrigeration systems

Ammonia is used as a refrigerant in the vast majority of new cold storage facilities and large process refrigeration applications, sometimes in combination with secondary refrigerants. IR systems typically use screw compressors and occasionally large reciprocating compressors. They are typically more complex than conventional CR systems as each solution is fully engineered for individual applications. IR systems cannot be purchased 'off the shelf' and due to the chemistry of ammonia, the use of copper pipe work and system components is not recommended. Therefore steel must be used which can be prohibitively costly smaller capacity systems. The main types of configurations are:

- **Direct expansion (DX) systems** where high pressure and relatively high temperature liquid refrigerant is drawn from the liquid receiver and throttled into the evaporator to meet refrigeration loads. The operational principal is similar to conventional CR DX systems except they often have a 'suction trap' to catch any liquid refrigerant that is carried over from the liquid receiver and 'sub-cooling circuit' to boil off liquid prior to returning to the compressor;
- **Gravity recirculation or flooded systems** differ as each evaporator is fitted with a surge drum that supplies low temperatures saturated liquid refrigerant to the bottom of the evaporator coil. The surge drum serves to separate out liquid and vapour, which allows the liquid to recirculate back to the evaporator, and the vapour to the compressor suction;
- **Over-feed systems** with a refrigerant pump that removes cold saturated liquid refrigerant from a low pressure suction accumulator and pumps it out to one or more evaporators. By design, more liquid refrigerant is pumped through the evaporator than can be evaporated in a single pass, hence the name 'overfeed system';
- **Two stage systems** with two stages of compression, which results in improved compression ratios. These systems can be configured with single stage, two-stage or indirect liquid expansion with single or multiple evaporator temperatures. Figure 91 provides a schematic of a two-stage compression system with two stages of direct liquid expansion where the evaporators can be configured as DX, flooded or over-feed systems.

Figure 91: Two stage compression system with two evaporator temperatures



Source: IRC, 2003a

7.3.2 Ammonia refrigerant (R-717)

Ammonia is a naturally occurring substance that has been successfully used as a refrigerant in industrial refrigeration plants for over 130 years[24]. It is a colourless gas that liquefies under pressure and has a pungent odour. Ammonia has negligible environmental impact with zero ozone depleting potential (ODP = 0), no direct global warming potential (GWP = 0) and low operational emissions due to high efficiencies (AIRAH, 2003).

Ammonia carries a B2 safety classification, meaning that it has a medium flammability and high toxicity risk. The ignition energy required to ignite Ammonia is 50 times higher than that of natural gas and will not burn without a supporting flame. Due to the high affinity of ammonia for atmospheric humidity it is otherwise rated as 'hardly flammable'. Ammonia is toxic to the skin and mucus membranes, but has a characteristic, sharp smell, which gives a warning below concentrations of 300 ppm. In amounts of 300 to 400 ppm, prolonged exposure will become unpleasant, and in amounts over 700ppm it can cause burns and serious damage to eyes. In amounts of 5,000ppm or above, exposure can be lethal to humans within five minutes (AIRAH, 2005 and A-Gas, 2005).

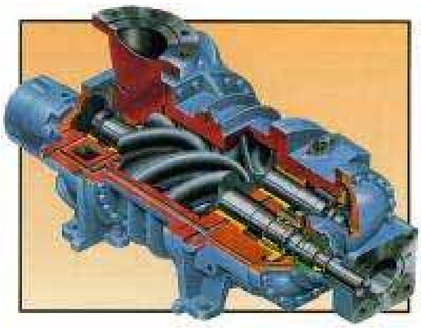
As a result of these hazardous characteristics Ammonia is effectively prohibited from use inside occupied spaces (except for small absorption machines), but it can be accommodated in unoccupied spaces or outside. To minimize workplace risks, strict standards and regulations for the construction and operation of ammonia refrigerating is essential which have hampered its use in many counties (Lindborg, 2008). This involves the use of leak containment practices, leak detection devices and emergency response measures in the event of an accident. *AS/NZS 1677.2-1998 Refrigerating systems part 2; Safety requirements for fixed applications* sets out restrictions on the use of class B2 refrigerants and *AS/NZS 2022-2003 Anhydrous ammonia-storage and handling* sets out provisions for safety equipment, handling and emergency plans. The additional safety precautions and equipment required can increase the initial capital cost by 200% or more compared to a conventional fluorocarbon refrigerant system.

7.3.3 Industrial refrigeration system components

IR applications use screw compressors and some large reciprocating compressors. Screw compressors are positive displacement compressors with less moving parts than conventional reciprocating compressors. Most of the heat of compression is transferred to oil flooding the chambers; reducing the operating temperatures and resulting in longer machine life and higher reliability. These compressors are normally directly coupled to electric motor drive as illustrated in Figure 92, hence operating at two or four pole speeds. The lower speed results in less stress hence longer machine life.

[24] The term 'natural' implies the origin of the fluids, i.e., they occur in nature as a result of geological and/or biological processes, unlike fluorinated refrigerants that are synthesized chemicals. Commonly used natural refrigerants are Ammonia, CO_2 and hydrocarbons.

Figure 92: Cut away diagram of an oil injected screw compressor



Source: IEA, 2005a

IR heat transfer equipment is traditionally constructed with a steel header assembly, connectors and tubes with aluminum fins. Stainless steel is being used in recent designs to increase the heat exchanger coefficient. Capacities of IR unit coolers are typically tested and certified in dry atmosphere (sensible heat) according to ENV 328, which is similar to fluorocarbon heat transfer equipment. An illustration of an IR evaporator is provided in Figure 93. Most other equipment used in IR refrigeration systems are similar in principal to larger commercial refrigeration installation with the exception of the use of steel or stainless steel instead of copper, and the mandatory use of leak detection equipment when ammonia is used as a refrigerant.

Figure 93: IR evaporator complete with condensate drain tray suited to a cold storage application

Source: Lu-ve Contardo

7.3.4 Packaged liquid chillers

Packaged liquid chillers are factory-made, prefabricated assemblies (not necessarily shipped as one package) with one or more compressor(s), condenser(s) and evaporator(s), with interconnections and accessories, designed for the purpose of cooling liquid such as water, brine or glycol. Packaged liquid chillers are specifically designed to make use of a vapour compression refrigeration cycle to remove heat from water and reject the heat to a cooling medium, usually via an air or water-cooled condenser. They are typically offered and rated in following categories based on leaving liquid temperature:

- Air conditioning with water from 2°C to 15°C;
- Medium temperature with brine from -12°C to 3°C, and
- Low temperature with brine from - 25°C to - 8°C.

The current Australian standard covering chillers is *AS/NZS 4776: 2008, Liquid-chilling packages using the vapour compression cycle*. This standard sets out a procedure for rating packaged liquid chillers and nominates minimum energy performances standards for chillers with capacities of 350kW and above.

The standard mainly applies to chillers used for space cooling with temperatures prescribed by ARI 550/590 or Eurovent Liquid Chilling Packages Certification Programme for air conditioning applications with water leaving temperatures from 2°C to 15°C. This study covers medium and low temperature packaged liquid chillers and are not covered within the scope within the scope of *AS/NZS 4776: 2008*.

Packaged liquid chillers are available in a wide range of capacities from 1kWr to around 1,000 kWr, where the cooling capacity is defined as the heat given off from the liquid to the refrigerant per unit time and is specified as the mass flow rate of the liquid multiplied by the difference in enthalpy of liquid entering and leaving the chiller. Cooling capacities are nominal and some suppliers offer correction factors that can vary as much as 30% to adjust the rated capacity to account for varying ambient temperatures from 5°C to 45°C; different liquid outlet temperatures; use of glycol or brine versus water and condenser water inlet temperatures for water-cooled models. Packaged liquid chillers use reciprocating, rotary, scroll, screw and some centrifugal compressors driven by electric motors and operate on fluorocarbon refrigerants, typically R407C or R410A and R134a with larger capacity units. Various air and water-cooled chillers are illustrated in Figure 94 to Figure 97.

.

Figure 94: Family of smaller air-cooled chillers from 1.4kWr to 175kWr

Figure 95: Large air-cooled chiller

Figure 96: Water-cooled chillers featuring hermetic scroll compressors

Figure 97: Water-cooled chillers featuring double screw compressors

Source: MTA

7.4 Market profile

7.4.1 Industrial refrigeration

Cold-chain logistics service providers with integrated refrigeration transport capabilities; major food retailers and food manufacturers with engineering expertise generally specify and control these large, complex IR systems. Installations are often linked to major capital projects and each system is engineered to suit specific application requirements. The installed base of IR applications is difficult to quantify, as the business is very project oriented, which means sales of ammonia (screw and some large reciprocating) compressors and refrigeration capacity vary significantly from year to year.

The best industry estimate is sales of 120 to 150 compressors per annum with approximately 30% applied in CS applications and the majority in industrial process applications involving chilling, freezing and ice making in primary and secondary stages of the Cold Food Chain.

The main ammonia compressor suppliers are Mycom (Mayekawa), Grasso, Bitzer, Johnson Controls (York, Frick, Sabroe and Stahl), Howden, Hitachi, Hanbell, Hasegawa and Bock.

IR systems and equipment are predominantly installed and serviced by contracting businesses supported by engineering teams that specialize in large commercial and ammonia refrigeration. The main businesses are:

- Gordon Brothers, a subsidiary of Hastie Group with manufacturing and Screw compressor rebuild facilities based in Victoria;
- Three stand alone regional businesses named Tri Tech Refrigeration all with similar backgrounds and profiles based in Victoria and SA, Qld and NSW;
- Cold Logic based in Adelaide who recently acquired Fourair in Victoria and are agents for Hanbell and Hasegawa Compressors; and
- Other regional businesses such as Scantec Refrigeration Technologies, Navaska, Excel Industrial Services and Acme Industrial Refrigeration Engineers all specialise in ammonia refrigeration.

There are independent consulting engineering businesses such as Oomiak Industrial Refrigeration, Beca Engineers Australia, ISECO Consulting Services and Minus 40 that offer independent consulting and project management to refrigeration users in the food, production and processing industries.

7.4.2 Cold storage facilities

The total volume of CS facilities operating in Australia is estimated to be at least 10,200,000 m^3 of which more than 80% use ammonia as a refrigerant (ES, 2008). The volume of CS facilities was derived from the quantitative study of Australian facilities for the Cold Hard Facts study and allowing for 4% growth per annum (ES, 2007). The large majority of cold storage is public warehousing meaning cold storage space that is available for public lease and can be counted from published records. In estimating the total cold storage volume both CSIRO Food Science (CSIRO, 2006) and Energy Strategies in Cold Hard Facts assumed private facilities to accounted for 20% of the total warehouse volume which is a conservative estimate relative to the estimate by the International Association of Refrigerated Warehouses (IARW) in 2006 that 30% of storage facilities in the US are private.

The size of facilities range from small warehouses of 2,800 m^3 to large distribution facilities over 200,000 m^3 with an estimated average size of 75,000 m^3 over more than 130 sites.

The major cold-chain logistics service providers are Swires, Oxford, Versacold and Toll that control over 70% of the total national storage capacity. Other service providers include Montague, Burnie Ports and Hobart. The peak industry body for the CS segment is the Refrigerated Warehouse and Transport Association of Australia Ltd (RWTA). AIRAH is the main industry body providing ammonia training and is actively participating in the development of new standards and codes of practice.

7.4.3 Packaged liquid chillers

The packaged liquid chiller market is made up of mainstream chiller suppliers such as Carrier, York, Trane, McQuay and Powerpax that dominate the large capacity air conditioning applications not covered within the scope of this study, and other suppliers that service smaller to medium sized air conditioning, process refrigeration and specialty applications. The main businesses supplying packaged liquid chillers of interest to this study are:

- Local manufacturers such as Matsu Chilling Systems, Powerpax, Aqua Cooler (IMI Cornellius), Sharpen Engineering (Subsidiary of Hastie Group), Fluid Chillers Australia and Serchill;
- Importers including MTA, Aermec-Luve, HLA Cooling and Champion compressors; and
- Specialty suppliers such as Fleming who specializes in the plastics and rubber industries and Witchurch Refrigeration and Air Conditioning that services off-shore petroleum applications.

The diverse range of industry applications and crossover between air conditioning and process refrigeration applications makes it difficult to accurately estimate the existing stock of process refrigeration chillers. For example refrigerated air-dryers supplied by Campion Compressors to cool compressed air have outlet water temperatures ranging from 5°C to 25°C. According to Eurovent standards these chillers fall into the air conditioning temperature range category of 2°C to 15°C.

The existing stock of packaged liquid chillers with medium and low temperature brine and glycol systems used in process refrigeration applications is estimated to be 9,000. This estimate was derived from the analysis undertaken in Cold Hard Facts where imported and manufactured data was dissected into small, medium and large capacities and then proportioned across industry applications. A summary of this analysis is provided in Table 42.

Table 42: Existing stock, capacities and average life-spans of chillers in process refrigeration applications

Application size	Cooling capacity (kWr)		Life-span	Existing stock
	Range	Weighted av.	(Years)	
Large	≥528 to <1055	706	25	1,200
Medium	≥110 to <528	339	20	5,800
Small	≥10 to <110	60	15	2,000
Total				**9,000**

Note: See Figure 90 for definition of application sizes

These estimates exclude around 3,600 Milk Vat chillers ranging from 30kWr to 80kWr discussed in more detail in Section 8, beer coolers covered in Section 9 and very small packaged liquid chillers below 10kWr.

7.5 Energy consumption and greenhouse gas emissions

Process refrigeration and cold storage applications consume an estimated 4,120 GWh of electricity per annum, which is equivalent to approximately 31% of total electricity used in Australia for non-domestic refrigeration and produces 4,140 kt CO_2-e of emissions. Table 43 below provides a breakdown of the energy consumption and emissions for industrial refrigeration systems, packaged liquid chillers and cold storage facilities.

Table 43: Electricity consumption and emissions from process refrigeration and cold storage applications in 2008

Application	Type of refrigeration equipment	Electricity consumption (GWh p.a.)	Emissions kt CO_2-e
Process refrigeration	Industrial refrigeration systems	630	634
	Packaged liquid chillers	2,855	2,875
	Sub total	*3,485*	*3,509*
Cold storage	Industrial refrigeration systems	630	634
Total		**4,115**	**4,144**

The estimate of 630 GWh of energy consumed per annum by CS facilities is derived from the quantitative research and analysis from Cold Hard Facts on the national cold storage capacity, and Specific Energy Consumption (SEC) benchmarks where SEC is a measure of energy consumption intensity of a cold storage facility in kWh/m^3 per annum. This study updated storage capacity estimates and undertook a more rigorous international review of SEC benchmarks. Multiplying cold storage capacity in m^3 by SEC in kWh per m^3 per annum provided an estimate of 630 GWh per annum. This estimate is consistent with CSIRO Food Futures estimate of 650 GWh per annum.

The balance of the installed base of IR equipment and its energy consumption is more difficult to quantify, as the business is very project oriented. The best industry indication is compressor sales, estimated at 120 to 150 compressors per annum with approximately 30% applied in CS applications and the majority in industrial process applications. These applications typically require greater refrigeration capacity; however have lower annual running hours than CS applications due to seasonality and factory shifts. For simplicity until further investigation is undertaken the total energy consumed by IR equipment used in process applications is assumed to be 630 GWh per annum, the same as CS.

The estimate of 2,855 GWh of energy consumed per annum by packaged liquid chillers is based on the estimated stock in Section 7.4.3 operating for 10 hours per day, all year round with an average COP of 3.0. This average COP accounts for chillers with air-cooled condensers and water-cooled units with higher COPs. A recent study by Energy Consult in 2008 involving a product profile of industrial chillers provided a top down estimated of electricity consumed by industrial chillers (EC, 2008). The study estimated industrial chillers consumed 3,336 GWh of electricity per annum of which 278 GWh per annum is consumed in Agricultural applications. The Energy Consult estimates are consistent with estimates from this study which include 256 GWh per annum for Milk Vat, 2,855 GWh per annum from packaged liquid chillers, and a portion of industrial refrigeration equipment operating as chillers. Based on a similar definition of industrial chillers to Energy Consult this study estimates they consume between 3,111 GWh and 3,741 GWh per annum.

The Greenhouse gas emission factor used to calculate emissions was 1.007 Kg CO_2-e/kWh, which is a weighted average (based on state population) of the NGERS state based full fuel cycle indirect emission factors for consumption of purchased electricity from the grid (DCC, 2008).

7.6 Opportunities for energy and greenhouse gas emission savings

7.6.1 SEC benchmarks for CS facilities

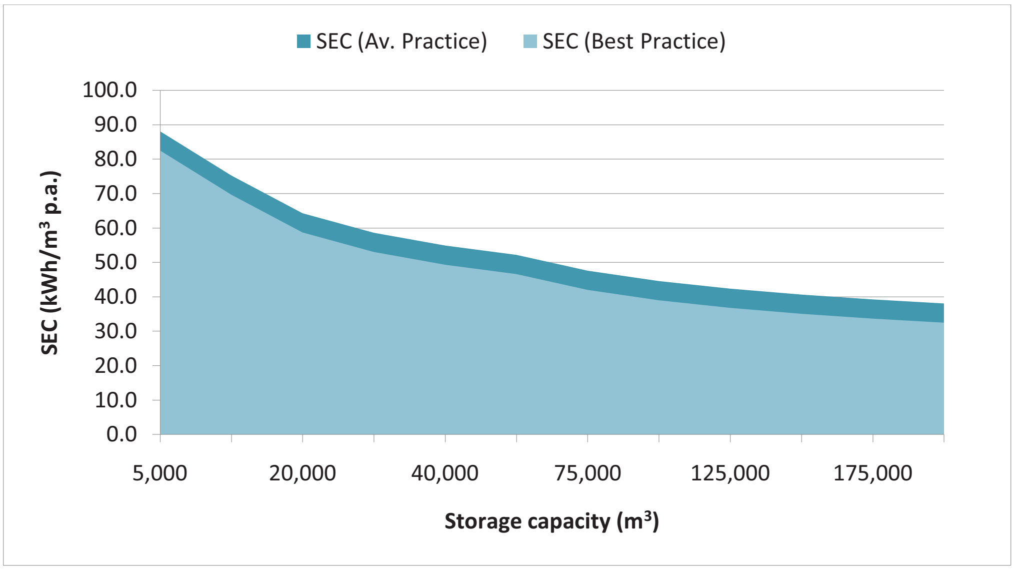
The most current and comprehensive benchmarking study on SEC was prepared for the California Energy Commission (CEC) in June 2008 (CEC, 2008). The study surveyed 67 public and 96 private refrigerated warehouses in California ranging from 5,600 m^3 to 170,000 m^3 and used a web-based benchmarking tool to assist operators to compare energy use of their warehouse with best practice performance and characteristics. The following regression equation was developed which found that SEC decreased significantly with cold storage volume.

$$\text{SEC (kWh/ft}^3\text{)}_{\text{average practice}} = 38.978 \times \text{storage volume}^{-0.2275}$$

Where storage volume is in ft^3 and can be converted into m^3 by multiplying by 0.0283.

The SEC average practice and best practice equations are illustrated graphically below for a range of storage capacities in m^3. The study found the difference between average and best practice performance varies from 6% for smaller warehouses, to 15% on large facilities and if extrapolated to the average size warehouse in Australian warehouses of 75,000 m^3, the savings potential is 12%.

Figure 98: SEC average and best practice in California



Source: CEC, 2008

The CEC study reported the model was consistent with previously reported results from studies conducted in New Zealand, the Netherlands, United Kingdom and United States. A summary of SEC kWh per m^3 per annum from the CEC Benchmarking study and other relevant reviews is provided below in Table 44.

Table 44: Summary of recent International SEC reviews

Source of information	SEC (kWh/m^3 p.a.)
Industry-wide studies	
New Zealand study, 2006	65.0
Previous New Zealand study	79.0
United Kingdom study, 2006	71.0
CSIRO Food Science, 2006	72.0
CEC Benchmarking study, 2008 (Californian average)	47.6
CEC Benchmarking study, 2008 (International review)	45.5
CEC Benchmarking study, 2008 (Best practice in California)	42.0
Average of industry wide studies	61.6
Individual case studies	
Cold Hard Facts, 2007 (160,000 m^3 Ammonia facility in Aust.)	32.0
Cold Hard Facts, 2007 (140,000 m^3 fluorocarbon R22 facility in Aust.)	39.0

Source: Werner et al, 2006; Mertz et al, 2004; CSIRO, 2006; CEC, 2008; Bosma, 1995; ES, 2007

The international studies provide a sound basis for estimating energy consumption in the cold storage industry in Australia. Although the averages vary from 47.6 to 79.0 kWh per m^3 per annum, the international review undertaken in the CEC study found an international average of 45.5 kWh per m^3 per annum. The SEC decreases significantly with cold storage volume and variations in international studies when compared to specific warehouses can be explained by this effect.

The Case Study in Cold Hard Facts of a 160,000 m^3 ammonia facility had a SEC of 32.0 kWh per m^3 per annum, which is around half the average of the industry-wide studies. Using the CEC regression equations, an equivalent sized warehouse would have an average consumption of 40.1 kWh per m^3 per annum, and a best practice of 34.5 kWh per m^3 per annum. The facility in the case study exhibited many of the best practice technology traits outlined in the CEC benchmarking study.

The average industry wide SEC of 61.6 kWh per m^3 per annum was used to estimate the energy consumption of cold storage facilities in Australia, with adjustments made to account for the lower efficiencies of the portion of systems operating on fluorocarbon refrigerants[25]. It should be noted that the stock of Californian cold storage warehouses has similar characteristics to Australian warehouses. For example, the total volume of Australian cold storage capacity is 10,200,000 m^3 versus an estimated

[25] This calculation assumed this average was for Ammonia Systems and adjustments were made to account for 20% of the Australian stock operating on fluorocarbon refrigerants that are estimated to be 15% less efficient.

14,000,000 m^3 in California; the range of sizes reviewed in the CEC study are similar to Australian warehouses and they hold similar produce[26]. The CEC regression equations are therefore a sound starting point for comparing performance of Australian warehouses until sufficient local data is collected.

7.6.2 Opportunities in industrial refrigeration

Ammonia systems are large complex systems where significant energy reduction opportunities can be achieved from optimising system performance. Energy use is determined by system configuration, operation and maintenance practices rather than efficient components alone. As a result it is potentially more beneficial to understand how the equipment is performing relative to peers or other benchmarks so corrective action can be taken in the form of optimization, maintenance or replacement.

Benchmarking and Key Performance Indicators (KPIs) are not new to the major cold-chain logistics service providers or blue chip companies in the Cold Food Chain in Australia. To date the benchmarking has been within corporations and unlikely to extend to smaller participants. Measuring performance is an essential process for any modern day operator, particularly during the current tough economic climate. Benchmarking is essential to fully understand how ones operation compares to peers with similar size facilities and applications.

The CEC study reviewed numerical KPIs such as SEC and peak demand as well as key characteristics that result in higher performance. The following energy conservation technologies were identified to contribute to best practice performance in California:

- **Upgraded insulation**; achieved by using thicker insulation and/or materials such as polyiscyanurate (PIR) with better thermal properties than expanded polystyrene (EPS);
- **Cool roofs**; which is an energy efficient roof surface that reflects and emits the sun's heat back to the sky instead of transferring it to the building below where the 'coolness' of the roof is measured by two properties, solar reflectance and thermal emittance (CRRC, 2009);
- **Efficient lighting technology**; either by design or use where some lighting systems are task driven and switched on when required;
- **Supervisory computer control** to optimize overall performance and effectively manage peak demands;
- **Thermo siphon oil cooling**; oil cooling is an integral and necessary part of industrial refrigeration screw compressor operation, thermo siphon oil cooling is a form of heat recovery and an efficient means of oil cooling (IRC, 2003b);
- Compressor, condenser and evaporator **variable frequency drives**;
- **Aggressive evaporative condenser design**; which is explained by a study undertaken by the University of Wisconsin in Madison into evaporative condenser control in IR systems in 2001, the project found a reduction in annual energy consumption by 11% as a result of design and control changes that optimized evaporative condenser sizing and head pressure control (IJR, 2001);
- **Floating head pressure;** and
- Automatic, **sensor controlled doors**.

[26] The USDA – NASS Statistics Division in January 2004 estimated that California has 309 million ft^3 and 139 million ft^3 of storage volume in public and privately owned warehouses, respectively. This equates to 12.7 million m^3 and 14.8 m^3 in 2008 assuming a 4% growth rate (CEC, 2008).

Many of these attributes can be seen in new facilities in Australia. There is an increase in the use of insulation with higher thermal properties, such as PIR with 150mm and 200mm wall thicknesses used on medium and low temperature coolrooms respectively. However it is claimed by industry sources that PIR is often used for insurance purposes rather than efficiency reasons and sometimes a mix of EPS and PIR is used to keep overall construction cost down. More efficient LED lighting is currently being trialled in leading facilities, particularly in low occupied areas, as they are easy to switch off and back on via motion sensors. New or upgraded lighting is designed to provide only the lighting level required for the task, rather than using standard lighting levels across a whole facility. Large facilities are using supervisory computer control with energy management software to monitor energy consumption and manage peak load demand. Compressors and fans are being fitted with variable speed drives on new and existing installations. More attention is being taken to moist air ingress through panel seals and doors. Automatic doors are common; however their effectiveness often depends on the type of facility and level of usage.

Additional energy saving benefits can be achieved with high-rise cold stores (8 or 9 pallets high) with fully automatic materials handling that reduces building transmission loads and provides increases product storage density requiring lower air recirculation and more stable air temperatures. This effect results in a reduction in fan power and energy consumption. The trade-off for improved efficiency is less flexibility with the range of products that can be stored.

A recent report by the British Frozen Food Federation (BFFF) highlighted a significant opportunity for the food service industry to reduce energy consumption by up to 15% by managing Cold Chain temperatures more effectively without reducing food quality or food safety (BFFF, 2009). In this study the data was collected from five cold storage facilities and eight frozen food factories representing small, medium and large companies, providing a wide range of frozen goods from poultry and seafood to vegetables and ice cream. The key areas of opportunity to improve efficiencies in the Cold Chain outlined in the report were:

- Raising cold store air temperature;
- Reducing the temperature difference between the warehouse and surge drum[27];
- Adjustment of suction pressure to suit conditions;
- Avoiding cold store air temperature fluctuations;
- Separating blast freezers and cold stores;
- Avoiding over cooling in blast freezers;
- Using variable speed evaporator fan control, and
- Using a flexible and effective defrost control system.

In summary the study found there is scope for tightening key control parameters on processing and storage facilities in the Cold Chain. European legislation requires companies to store, handle and transport frozen products at -18°C or below, and the study found in some instances there was scope to increase air temperature by about 6°C giving rise to energy savings of approximately 15%. This may have limitations is certain applications such as cold storage facilities that operate at lower temperatures during off peak times to build up thermal energy to cut energy consumption during peak tariff times. Where applicable, most of these key opportunities could be effectively managed with a set of energy management KPI's for different applications or food types and be adopted with minimal cost and short

[27] The surge drum is typically used on flooded systems and serves to separate out liquid and vapor refrigerant, which allows the liquid to recirculation back to the evaporator, and the vapor to the compressor suction.

paybacks. Northwest Food Processors Association (NWFPA) in the USA reported energy savings of more than 20% by introducing energy management KPIs and assigning an energy champion to oversee the plant energy efficiency program (IEA, 2005b).

Online benchmarking (OLB) is evolving as a very effective method of introducing industry wide benchmarks and KPIs. An example of this is a new Internet based system funded by the Department for Transport in the UK (DT, 2009). It allows transport operators to externally and anonymously benchmark their operations and establish if they are a 'best in class performer'. It also helps to identify areas for improved performance and financial savings. The online performance management tool allows operators to compare their performance across a range of eight KPIs covering aspects such as fuel, safety, vehicle utilization and customer satisfaction. A similar approach could be adopted for the Cold Food Chain with a range of energy management KPIs and guidance on best practice energy conservation technologies.

IR systems are capital intensive and typically have long life-spans of between 20 and 30 years. There are significant energy reductions that could be achieved by migrating the existing stock of cold storage facilities to best practice. Given the long life-span of IR equipment this will take a decade and even longer if companies do not fully understand the operational characteristics and benefits of a '*best-in-class*' facility. The CEC study found the difference between average and best practice performance varies from 6% on smaller warehouses to 15% on large facilities: equivalent to a 12% energy saving when applied to the average sized warehouse in Australia of 75,000 m^3. This equates to a difference of 76 GWh per annum across the industry. An online benchmarking tool for Australian CS facilities could stimulate this process and promote the range of energy efficiency measures identified by the BFFF and similar studies.

7.6.3 Packaged liquid chillers

Technologically there are number of options that can be used to improve the efficiency of packaged liquid chillers at the design stage. These include intelligent control systems, improving heat transfer, use of efficient compressor, fan and pump technology, use of a prime mover[28], and use of "free cooling" (EC, 2009):

- Intelligent control systems can regulate all aspects of chiller operation to ensure that supply just about meets the demand. The control system can be used to control water flow, output of prime-mover, flow control of coolant, improve temperature sensing at end-use and synchronising changing cooling requirements at end-use point with the output of the chiller;
- Improved heat transfer can be achieved by minimising heat losses due to leakages and poor insulation, use of material with better heat transfer and corrosion resistance characteristics (e.g. grooved tubes/pipes that offer larger heat transfer area for a given diameter and thickness), and, improved and unrestricted flow of liquid;
- Use of inherently more efficient compression technology can improve the efficiency of the chiller. Centrifugal and scroll types of compressors tend to be more efficient than the reciprocating type that is commonly used. In addition, optimum sizing and use of efficient prime mover can also improve the energy performance of the chiller;
- Air-cooled chillers have condenser fans; the use of more efficient motors such as EC motors and improved fan blade technologies is particularly relevant to smaller chillers with single-phase fan motors. For further detail refer to Section 4;
- Use of more efficient motors on pumps will improve the efficiency of the chiller. This is a subject under review in the Industrial Equipment study commissioned by Sustainability Victoria;

[28] A prime mover is a gas turbine, reciprocating engine or steam turbine that can be used on large chillers in conjunction with an electric motor coaxially arranged on a common shaft to drive the compressor.

- Use of “free cooling” is yet another way of minimising energy input to the chiller. Free cooling is particularly useful for chillers in process applications, as they often operate irrespective of weather conditions. Free cooling refers to use of lower ambient temperature to pre-cool the make-up or returning water to the chiller. Free cooling can be achieved with a temperature differential of as little as 1°C i.e. when the temperature of returning water is 1°C higher than the ambient temperature.

From an operational point of view, in most cases the maximum efficiency is achieved when the chiller is running at approximately 70% to 75% of its rated load and the lowest entering condenser water temperature, based on design. Therefore designing and installing a compressor that can operate at 70 to 75% of its rated load will save energy compared to a system that is grossly over sized or undersized.

7.7 Australian standards

7.7.1 Industrial refrigeration

The main Australian standards relevant to industrial refrigeration or ammonia refrigerant are as follows:

- *AS/NZS 1677.2-1998 Refrigerating systems part 2; Safety requirements for fixed applications.* This standard specifies safety requirements for all refrigerants including ammonia, in terms of the design, construction, installation and inspection of refrigerating appliances, systems and ancillary equipment;
- *AS/NZS 2022-2003 Anhydrous ammonia-storage and handling* specifies requirements for the design, construction, location, operation and testing of systems for the storage and handling of anhydrous ammonia. It also sets out requirements for the management of emergencies and fire protection involving anhydrous ammonia.

Following a recent survey by WorkSafe Victoria which identified ammonia as the second most hazardous material in Victoria, an Ammonia Task Force has been established to develop an Ammonia Code of Practice for Victoria. The task force is chaired by AIRAH and members include WorkSafe Victoria, hazardous goods staff from the Metropolitan Fire Brigade and Country Fire Authority, BOC, Orica and various industry users with large IR plants. The Code of Practice will encompass Acts, regulations and codes pertaining to ammonia design and installation, emergency plans, maintenance, detection systems, training and auditing. The document is nearing draft stage, after which it will go to industry for comment and is likely to be adopted by other State regulators.

None of these standards relate to the efficiency of IR equipment, they primarily address safety, handling and other environmental aspects when using ammonia as a refrigerant. Other relevant standards activities in the commercial refrigeration industry include growing interest in EN 378: 2008, Refrigerating Systems and Heat Pumps - Safety and environmental requirements, as the governing industry standard for refrigerating equipment and refrigerants. The ME006 Standards Committee is considering the possibility of adopting ISO 5149: 2009 Refrigerating systems and heat pumps - Safety and environmental requirements to replace AS/NZS 1677-1998 Refrigerating systems. Where ISO 5149: 2009 is essentially a mirror image of EN 378-2008 with references to EU directives removed and other changes to make it more suitable as an International Standard.

The timing of this review complements other industry activities such as a drive to develop a Total Environmental Warming Impact (TEWI) rating methodology standard for refrigeration system that takes into account both direct and indirect greenhouse emissions. Although TEWI is referred to quite widely in Europe, it is not well known or consistently applied in Australia and New Zealand. An industry-government TEWI working group plans to review current information on this subject and advise the ME006 on the suitability of the TEWI methodology used in ISO 5149: 2009.

7.7.2 Cold storage refrigeration

Following an investigation into an explosion and fire that destroyed a cold storage facility that used hydrocarbon as a refrigerant in Tamihere, near Hamilton New Zealand, the IPENZ (Institute of Professional Engineers of New Zealand) published Practice Note 15; Coldstore Engineering in New Zealand, a design guideline for cold storage facilities (IPENZ, 2009). The purpose of the guideline was to cover fire engineering recommendations from the investigation and encompass economics, insurance, structure, insulation, refrigeration, electrical, operations and maintenance of aspects of coldstores.

7.7.3 Packaged liquid chillers

The current Australian standard for chillers is *AS/NZS 4776: 2008, Liquid-chilling packages using the vapour compression cycle.* This Standard sets out a procedure for rating packaged liquid chillers mainly used for space cooling with temperatures prescribed by ARI 550/590 or Eurovent Liquid Chilling Packages Certification Programme for air conditioning applications with water leaving temperatures from 2°C to 15°C. This Standard covers air and water-cooled packaged liquid chillers and sets out minimum energy performance standards for chillers with a cooling capacity of 350 kW and above. This standard has scope to be expanded to include smaller chillers and other temperature ranges such as process refrigeration applications with lower liquid leaving temperatures.

Packaged liquid chillers used in commercial buildings are also covered under building directives as well, which are prescribed under *Section J 5.4, Heating and Chilling Systems* of the Building Codes of Australia (BCA). This standard prescribes minimum energy efficiency ratios for chillers and historically covered chillers above 125kW capacity. The draft 2010 BCA has been amended to cover chillers up to 350 kWr capacity that are part of an air-conditioning system (BCA, 2009). The standard has been amended to complement *AS/NZS 4776: 2008* and does not cover medium and low temperature packaged liquid chillers that are of interest to this study.

7.8 Overseas policies and standards

7.8.1 Industrial refrigeration

The main overseas standards relevant to industrial refrigeration or ammonia refrigerant are as follows:

- *EN 378:2008, Refrigerating Systems And Heat Pumps - Safety And Environmental Requirements*, with Parts 1 to 4 that cover various safety aspects associated with the use of all refrigerants including ammonia;
  - Part 1: Basic requirements, definitions, classification and selection criteria;
  - Part 2: Design construction, testing, marketing and documentation ;
  - Part 3: Installation site and personal protection;
  - Part 4: Operation, Maintenance, Repair And Recovery;
- *ANSI/IIAR 2-2008, Equipment, design and installation of closed-circuit ammonia mechanical refrigerating systems.* Where American National Standards Institute is the accredited standards developer and the International Institute of Ammonia Refrigeration is responsible for technical content of the standard. A 2009 draft is currently under review that proposes a new standard to include criteria for the safe start-up and commissioning of closed-circuit ammonia refrigerating systems.

In North America the US Department of Labor, Occupational Safety and Health Administration bring together the wide range of State based Occupational Safety and Health Plans, rules and directives that address Ammonia refrigeration. They provide an overview of these and a list of good engineering practices, which apply to many ammonia refrigeration facilities (USDL OSHA, 2009). None of the national consensus standards related to the energy efficiency of ammonia refrigeration.

No international energy efficiency agencies or regulators have identified IR as an opportunity to introduce MEPS. Current North American and European policies are focus on safety, handling and other environmental aspects of using ammonia as a refrigerant. There is a wide range of commercially available standards and technical papers to provide refrigeration plant operators, engineers, and managers with information on improvements to the energy efficiency of their IR systems. The main bodies providing this information are:

- American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), offer a wide range of publications including the 2006 Handbook for Refrigeration that is widely used by Australian IR engineers;
- International Institute of Refrigeration (IIR), offer a wide range of technical publications to enhance the performance of IR systems (IIR, 2008);
- International Institute of Ammonia Refrigeration (IIAR), offer a wide range of technical bulletins and guidelines plus ASHRAE and ANSI standards, the Ammonia Data Book and links to IR suppliers;
- Industrial Refrigeration Consortium (IRC) is a collaborative effort between the University of Wisconsin Madison and industry and provides range of educational material on IR technologies including an Energy Efficiency Guidebook;
- Industrial Efficiency Alliance (IEA), a collaborative organization that assists Northwest industries in the US to use energy more efficiently. The IEA published the Industrial Refrigeration, Best Practices Guide, 2004 and provide a number of case study testimonies of achievements with efficiency improvements with IR systems.

7.8.2 Packaged liquid chillers

There are no MEPS for chillers used in refrigeration applications. Other relevant international performance regulations are found in the USA, Canada and Chinese Taipei. However, these regulations mainly relate to the performance of chillers used for space cooling. The USA, Canada and Chinese Taipei all test chillers to ARI 550/590 or the equivalent. The MEPS levels of the USA and Canada are the most stringent international standards, with Chinese Taipei having come into line with these standards in 2005. The USA and Canadian MEPS is specified in terms of minimum COP and Integrated Part Load Value (IPLV), while the Chinese Taipei is applied to the COP only.

The USA uses a building code (ASHRAE Standard 90.1) to enforce the MEPS for chillers and has had standards in place since 1993. The USA have required that state and local governments to update their commercial building energy efficiency codes to be at least as stringent as ASHRAE Standard 90.1-1999 by 2004. By using the building code to regulate chillers, the regulation is restricted to the installation of chillers into new buildings and consequently does not affect the replacement market. These regulations specifically exclude chillers used in process applications.

In Europe, the Eurovent Liquid Chilling Packages Certification Program is used as a voluntary performance standard. This program applies to air-cooled, liquid-cooled or evaporative-cooled chillers used for air conditioning and refrigeration applications based on the following liquid leaving temperatures:

- Air conditioning with water from 2°C to 15°C;

- Medium temperature with brine from -12°C to 3°C;
- Low temperature with brine from - 25°C to - 8°C.

This program only applies to 50 Hz units and is the primary International standard used for certifying chillers used in process refrigeration applications.

7.9 Recommendations

IR is essential for the production, handling and storage of many food products consumed today. Although it is an inherently energy-intensive, careful application of engineering principles in design and operation can lead to significant improvements in energy efficiency. These energy reduction opportunities are in the hands of engineers and their ability to identify, implement and maintain best practice technologies, which are sometimes seen as intellectual knowledge to be guarded, as it is a form of competitive advantage over competitors.

The establishment of an Online Benchmarking (OLB) tool would provide an effective mechanism for collecting reference data on energy-use by individual warehouses while sharing best practice technologies in order to transforming the operational performance of the existing stock of CS facilities. Performance data collected from this source amongst others should then be used to set benchmark targets and key performance indicators for appropriate categories of facilities. Identification and communication of best practice characteristics will encourage the use of variable speed drives on compressors, condenser and evaporator when applicable and adopt other practices similar to those discussed in Section 7.6 of this document.

Industry bodies such as the RWTA and AIRAH would be well placed to effectively implement, manage and communicate this type of program. Their existing members include the large majority of participants in the CS and IR industries and have relevant specialised technical expertise. AIRAH is the primary body providing Ammonia training in Australia and is actively involved in developing an Ammonia Code of Practice for Victoria.

For packaged liquid chillers, horizontal measures on components such as compressors and fans discussed in Sections 3 and 4 and will have a positive impact on the performance of these products. At this stage, no additional voluntary or mandatory measures are recommended for chillers designed for refrigeration applications.

As a result the recommendations include:

- That government and industry organisations combine to establish an online benchmarking facility to provide best practice information to the cold storage industry;
- Government and industry should set appropriate benchmark targets and key performance indicators by a date not later than 2011, based on the data on individual sites collected through this tool, and other sources;
- Governments should further investigate how such benchmarks and key performance indicators should be applied in order to be most effective, including through voluntary agreements with industry or regulation.

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8 Milk Vat (MV) Refrigeration

Milk vat refrigeration consumes an estimated 685 GWh of electricity per annum in Australia and New Zealand (around 4% of total commercial refrigeration energy) in dairy farm applications where refrigeration energy is required to chill fresh milk prior to pick up by bulk milk tankers and delivery to processors.

The purpose of this section is to provide a description of the equipment types, market profile with estimates of electricity consumption including Greenhouse gas emissions and discuss key energy reduction opportunities.

8.1 Description of technology

Dairy farmers are required to chill fresh milk from 34°C to 4°C prior to pick up by bulk tankers. The milk is refrigerated in large insulated vats, ranging in capacity from 5,000 to 40,000 litres in either horizontal or vertical configurations (see illustrations below). The tank capacity and type depend on herd size, calving pattern, frequency of milk collection, required milk quality, power supply, water availability and future plans for development.

In order to guarantee milk quality standards in Australia, the milk must be chilled in less than 4 hours and be stored at 4°C for no more than 3 days. In New Zealand milk is chilled to 7°C, with the balance of chilling undertaken in centralized processing factories. There are some international markets are placing pressure on NZ farmers to chill to 4°C. There are two common milk cooling methods used on dairy farms today, each with its own advantages and disadvantages:

- Direct expansion (DX) cooling;
- Indirect cooling systems.

These methods are discussed in detail in the following sections.

Figure 99: Horizontal milk vat

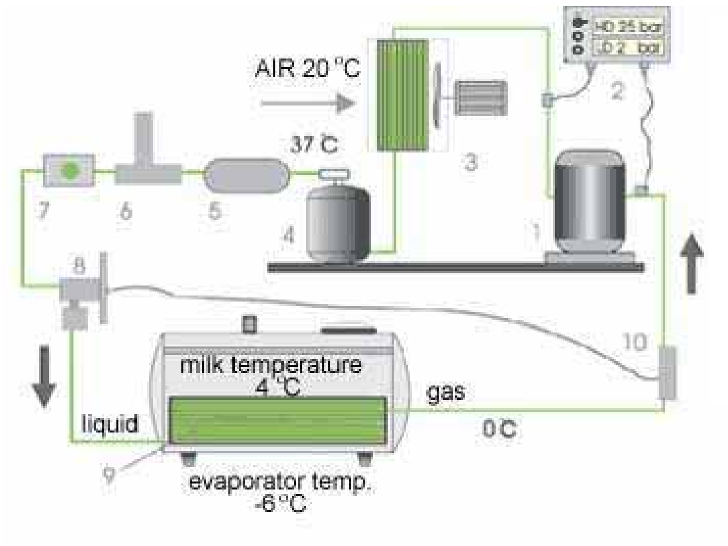
Figure 100: Vertical milk vat

8.1.1 Direct expansion (DX) cooling

Direct expansion systems, commonly referred to as DX systems have pipes or plates carrying refrigerant, which are welded directly to the exterior of the milk chamber. The milk is cooled in the vat and the refrigerant flowing through the dimple plate evaporator creates the refrigeration effect on the milk. A schematic diagram of a DX system is provided below in Figure 101, which itemises all of the components in the condensing units, and Figure 102 illustrates the use of a packaged air-cooled condensing unit with a MV. Most DX systems in Australia use very traditional refrigeration technology (belt driven open drive condensing units), which are discussed in more detail in section 8.1.4.

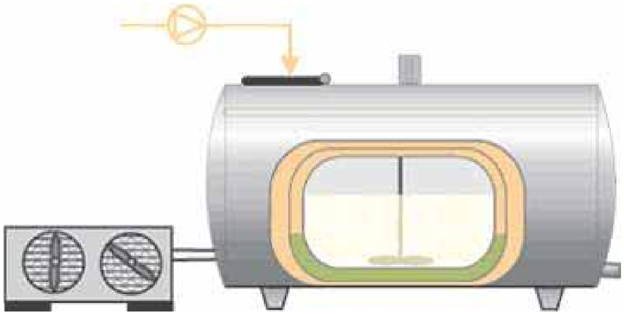
This style of system is commonly used on small and medium size dairy farms. MV tanks are typically insulated with 50 mm thick Expanded Polystyrene (EPS) and contain an agitator motor to stir the milk and maximise heat extraction. The temperature is controlled with a thermostat that switches off the refrigeration system when the milk reaches the 4°C set point.

Figure 101: Schematic of DX cooling system



1. Hermetic compressor
2. Dual pressure controls
3. Air cooled condenser, fan and motor
4. Liquid receiver
5. Filter drier
6. Solenoid valve
7. Sight glass
8 and 10. Thermostatic expansion valve

Figure 102: MV and packaged air-cooled condensing unit



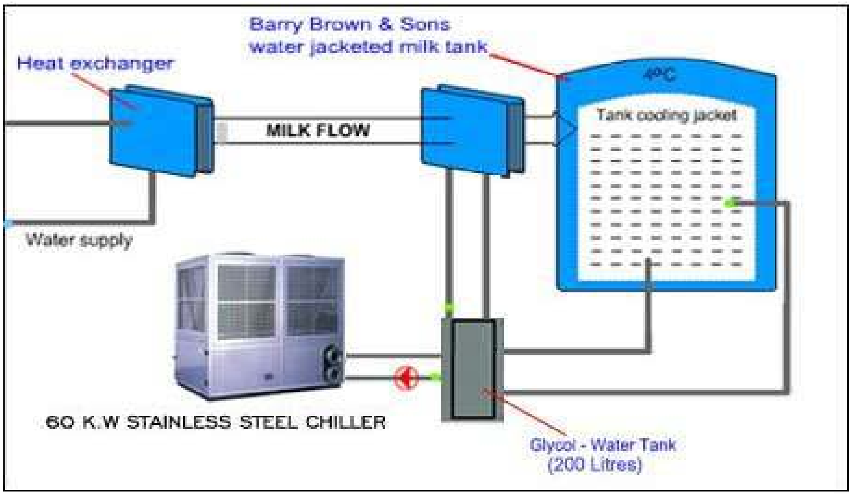
8.1.2 Indirect cooling systems

Indirect cooling systems have an intermediary fluid, such as water or a food grade glycol solution, which provides the refrigeration effect on the milk in the vat. The refrigeration system is not directly attached to the vat; a packaged chiller or ice bank cools the fluid that is pumped through the vat. This fluid can either be cooled at the time of demand or be refrigerated at off-peak times and stored for use at milking.

Indirect cooling systems are sometimes described as direct cooling systems as they cool the milk directly in the vat. However, direct ice bank chiller systems that spray ice water on the outer surface of the milk vessel are classified in this document as indirect cooling systems.

Basic indirect cooling systems are generally less efficient than direct expansion systems due to heat transfer losses from the secondary fluid and running the circulation pump. The efficiency of these systems can be improved by adding a pre-cooler; a schematic diagram of a system with a double stage pre-cooler is provided in Figure 103, and pre-coolers are discussed further below.

Figure 103: Milk vat system with double stage pre-cooler



8.1.3 Pre-coolers for DX and indirect cooling systems

Milk can be entirely cooled in the MV, chilled before it hits the vat or be cooled using a combination of pre-cooling and vat cooling. Most farms pre-cool milk before it enters the MV, which saves energy by reducing the direct cooling load and electricity consumption. Pre-coolers can be used on both direct expansion and chiller systems.

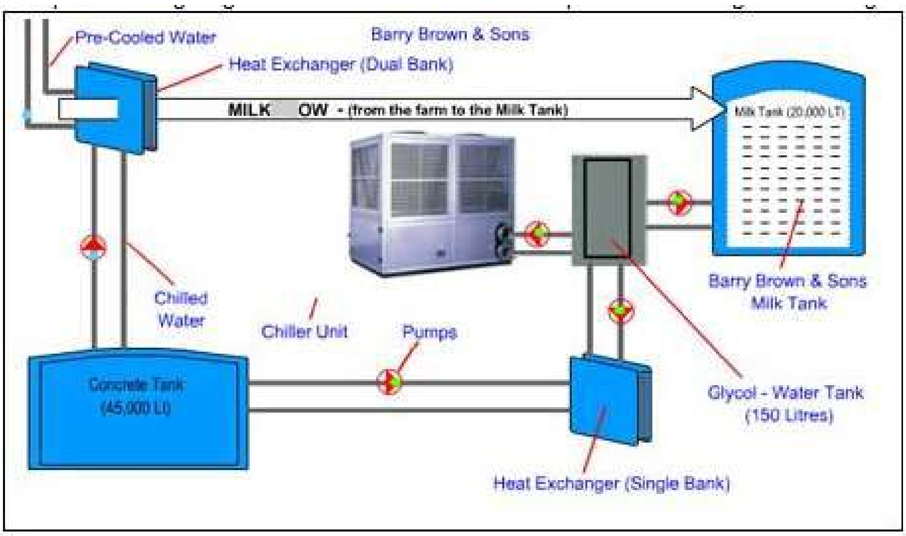
A plate heat exchanger that uses bore or surface water to remove heat and pre-cool milk from 34°C to around 25°C is the simplest and most cost effective type of pre-cooler.

Double stage pre-cooling can be used to enhance efficiency, where 25°C milk from the first stage (plate heat exchanger) is cooled to 6 or 7°C. Figure 104 provides an illustration of an indirect cooling system with double stage pre-cooler and Figure 104 illustrates the use of a thermal storage tank for an off-peak cooling. These types of systems are typically used on larger dairy farms where bulk quantities of milk are harvested and fast cooling is necessary to maintain milk quality.

The chilled water can be produced on demand or overnight on off peak electricity rates and can be produced in a number of ways including:

- Cooling towers that cool water by transferring heat from water into the air;
- Thermal stores such as an insulated water tanks that cools water overnight using off peak discounted rates;
- Ice banks that generate ice along evaporator coils during off peak times. During milking, water is circulated from the ice bank to the pre-cooler back to the ice bank to be chilled again;
- Instant chillers that use a refrigeration system to provide instant chilled water on demand for the pre-cooler.

Figure 104: Milk vat system with storage tank for off peak cooling



8.1.4 Chillers, condensing units and compressor types

Air-cooled condensing units, usually located outside the milking shed for improved compressor and condenser ventilation, service direct expansion systems. Indirect cooling systems are typically serviced by packaged chillers systems containing tube-in-tube pressure vessel or plate heat exchangers.

The main types of compressors used in MV systems include:

- Hermetic reciprocating and scroll type;
- Semi-hermetic;

- Belt driven open-drive type.

Hermetic and semi-hermetic compressors are found in condensing units and packaged chillers. Traditional belt drive systems are typically used on DX systems, illustrations of the three main types of refrigeration systems are provided below.

Figure 105: Belt driven open-drive unit (remote condenser not shown)

Figure 106: Hermetic air-cooled condensing unit

Figure 107: Packaged chiller unit

8.2 Market and greenhouse gas emissions profile

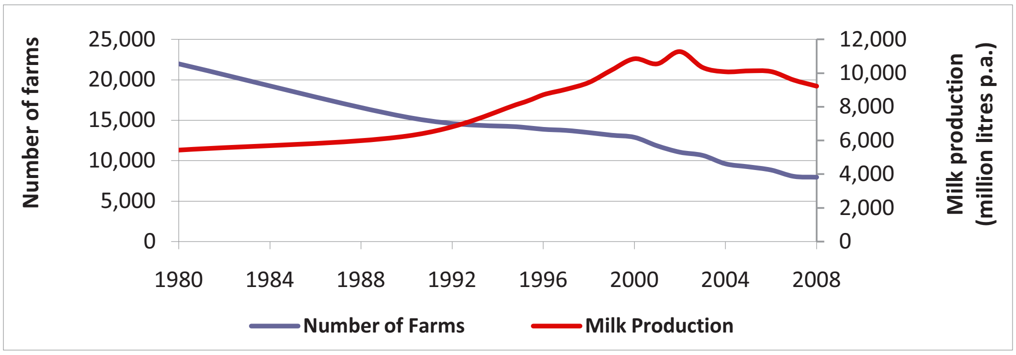
8.2.1 Market profile, Australia

The Australia's dairy industry is one of the three most important rural industries, with a farm gate value of $4.6 billion in 2007/08. Dairy ranks fifth in agricultural exports, valued at $2.9 billion.

The dairy industry has seen a lot of farm consolidation over the last two decades with farm numbers declining from 21,994 in 1980 to 7,953 in 2008. This decline in farms has not greatly affected milk production which almost doubled over the same period and has a direct correlation with refrigeration cooling demand. The national trend of the number of farms and milk production is graphically illustrated in Figure 108. The average milk production per farm has grown from 247,000 litres per annum in 1980 to 1,160,000 in 2008. This consolidation of farms has resulted in larger and more efficient MV systems.

The majority of dairy farms and MV business is located in Victoria (68% in 2008) and all main suppliers have their head offices in Victoria. Table 45 below provides a dissection of farms by state.

Figure 108: National dairy farm and milk production in Australia



Source: Dairy Australia, Australian Dairy Industry in Focus, 2008

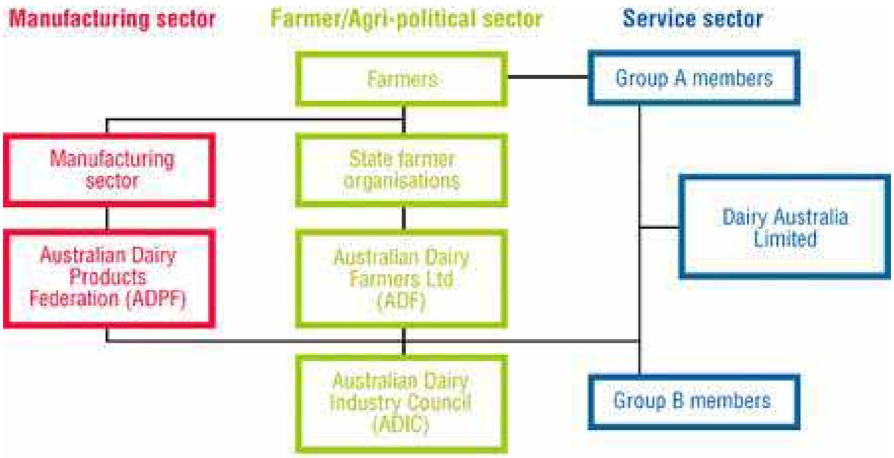
Table 45: Number and proportion of farms by State, 2008

	NSW	VIC	QLD	SA	WA	TAS	National
Number	886	5,422	664	332	186	463	7,953
%	11%	68%	8%	4%	2%	6%	100%

Source: Dairy Australia, Australian Dairy Industry in Focus, 2008

The Australian dairy industry comprises a number of organizations that represent different sectors of the industry; the industry framework is illustrated in Figure 109. Dairy Australia is the peak body for the industry with around 6,000 members and invests about $30 million of Dairy Service Levy payments and $15 million of taxpayer funds in a range of educational and continuous improvement services for the Australian dairy industry. A recent project sponsored by Dairy Australia was the Milk Harvesting Centre, Cowtime Project that encompassed milk harvesting research to assist farmers improve practices, save energy and reduce costs. The project provided a series of guidelines and case studies, which are used as references and testimonies in this study.

Figure 109: Australian dairy industry framework

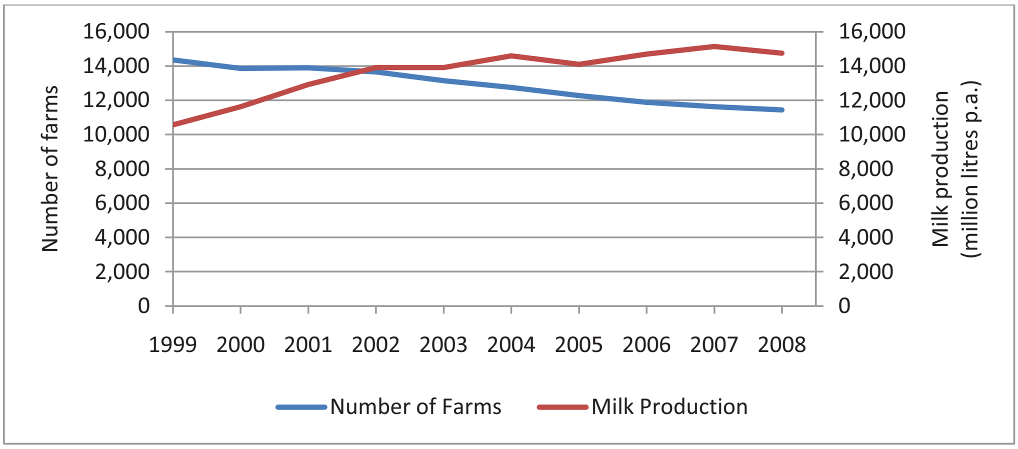


8.2.2 Market profile, New Zealand

The New Zealand dairy industry is a significant industry sector that represents around 20% of all New Zealand merchandise exports by value. The annual liquid milk production in New Zealand is more than 14 billion litres of which around 95% is exported making New Zealand one of the world leading milk exporters.

The New Zealand dairy industry has seen similar trends in the consolidation of farms to Australia over the last two decades with farm numbers declining from 18,540 in 1974 to 11,436 in 2008. Similarly this decline in farms has not greatly affected milk production, which has increased by more than 40% over the last decade. Annual milk production has a direct correlation with refrigeration cooling demand and is approximately 60% higher than Australian volumes. The national trend of the number of farms and milk production is graphically illustrated in Figure 110. The average milk production per farm has grown from around 700,000 litres per annum in 1980 to 1,290,000 in 2008, which is similar to current Australian farms with an average volume of 1,160,000 litres per annum in 2008. New Zealand has a higher proportion of DX systems than Australia, which also tend to be smaller due to the 7°C chilling requirement. The consolidation of farms has not caused a significant migration to chiller technology.

Figure 110: National dairy farm and milk production in New Zealand



Source: New Zealand Dairy Statistics (LIC, 2008)

New Zealand's dairy industry has a proud heritage that dates back to 1814 and has seen many changes in industry structure; today the key industry representative is the Fonterra Co-operative Group that is co-operatively owned by around 96% of New Zealand dairy farmers. Fonterra is a marketing organisation and leading exporter of dairy products, responsible for one third of International dairy trade. Another key industry stakeholder is the Dairy Companies Association of New Zealand (DCANZ), which claims to represent the collective public policy interests of its members such as milk production/manufacturing, trade and marketing of dairy products, including issues affecting the public perception of dairy products. The key members of DCANZ are Fonterra Co-operative Group Ltd, Tatua Co-operative Dairy Company, Westland Milk Products, Goodman Fielder Ltd, Open Country Cheese and Gisborne Milk Co-operative. The large majority of the dairy industry and suppliers is concentrated in the North Island, which accounts for around 79% of farms in 2008, with the South Auckland and Waikato regions representing over 30%.

8.2.3 Equipment and component suppliers

MV equipment is very specialized, with approximately 50% of vats imported and condensing or chiller rack system locally made to suit Australian ambient conditions and local electrical supplies. The following are the major equipment suppliers of refrigerated milk vats and equipment in Australia:

- Barry Brown & Sons;
- Bou-Matic Milk Vats;
- Dairy Tech (distributor of Packo Fulwood);
- Alfa Laval;
- Westphalia Milk Vats.

The key compressor suppliers are Bitzer (belt drive and semi-hermetic), Danfoss (formerly Maneurop hermetic reciprocating) and Copeland (hermetic scroll).

8.2.4 Existing stock

The existing stock and mix of equipment was estimated by dissecting the number of dairy farms into two capacity sizes and then into system types with the assistance of key industry sources that supply chillers, DX systems and compressors to the MV market. Table 46 shows the breakdown of the existing stock of MV systems in Australia.

Belt drive units connected to direct expansion systems have been the most popular choice in the past. The life-span of MV systems varies significantly, from smaller farms that can keep belt drive system operating for 20 years or more, to modern Co-op facilities replacing equipment every 10 years. Chiller technology connected to indirect cooling systems containing hermetic and semi hermetic compressors is rapidly gaining acceptance and current penetration of the existing stock is estimated to be greater than 45%.

This technology trend will continue with the further consolidation of farms, as larger capacity Milk Vat systems are more suited to indirect cooling systems using packaged chillers. However, with the number of farms in Australia continuing to decline and constraints on investment in new equipment (of between $55,000 and $155,000 per dairy) the transformation will take time.

Table 46: Existing stock of farms and equipment

Type of cond. Unit/compressor	Type of MV system	Size of farm	Nominal kWr	Proportion	Number of farms
Open drive units	Direct expansion	Large	22 to 34kW	7%	529
		Small to mid	7.5 to 11kW	47%	3,754
Hermetic compressors (Recip. or scroll)	Chiller with indirect cooling	Large	22 to 34kW	10%	796
		Small to mid	7.5 to 11kW	25%	1,988
Semi-hermetic compressors		Small to large	11 to 34kW	11%	885
				100%	7,950

8.2.5 Trends and projected growth

Dairy Australia, the peak body for the dairy industry described the outlook as positive with some challenges. In a recent review they predicted local growth to remain constrained by rising input costs; uncertain climatic conditions; limited national herd growth; and the impact of government policy. The average growth per annum of milk production from 1980 to 2008 was 2.5%. The lack of investment in national herd growth will limit future growth and is likely slow investment in MV equipment.

8.2.6 Energy consumption and greenhouse gas emissions profile

In Australia, MV systems consume an estimated 390 GWh of electricity per annum chilling milk, with chillers representing 60% and DX systems the balance. The energy consumption was calculated by assuming the existing stock of MV systems operated 8 hours per day, all year round. The existing stock and mix of equipment was estimated by dissecting the number of dairy farms into two capacity sizes and then into system types with the assistance of key industry sources that supply chillers, DX systems and compressors to the MV market. The total input power of chillers included the power to operate the glycol pump, as it is an integral part of the packaged chiller. Other equipment used on farms in milk cooling processes includes motors that drive milk vat agitators, milk pumps and water pumps. These components are external to the primary refrigeration system and have not been included in the energy consumption estimates.

Table 47 provides a breakdown of the energy consumption and emissions of each type of MV systems in Australia, which shows chillers consume an estimated 276 GWh per annum. A recent top down study by Energy Consult on Industrial Chillers in 2008 estimated agricultural chillers consumed 278 GWh of electricity per annum (EC, 2008).

This top down estimate correlates with the bottom up estimate for MV chillers shown below in Table 47 as the large majority of agricultural chillers are MV chillers.

Table 47: Electricity consumption and emissions in 2008

Equipment Type	Electricity Consumption GWh p.a.	Emissions kt CO_2-e
MV chillers	276	278
Direct expansion cooling MV	182	183
Totals	458	461

MV systems in New Zealand consumed an estimated 295 GWh of electricity in 2008, which amounts to 10% of total electricity used in New Zealand for non-domestic refrigeration. This estimate was calculated based on an average size unit with an input watts of 11,500 and operating 8 hours per day, 280 days per year. The greenhouse gas emission from MV systems in New Zealand is estimated at 177 kt CO_2-e in 2008 based on an indirect emission factor of 0.6 Kg CO_2-e/kWh. The greenhouse emissions from Australian MV systems in Australia are estimated at 393 kt CO_2-e in 2008 based on a national average indirect emission factor of 1.007 Kg CO_2-e/kWh. With Victoria representing 68% of Australian dairy farms actual emissions could in fact be more than 10% higher than estimated due to the higher indirect emission factors for electricity consumed on the Victorian electricity grid.

8.3 Energy reduction opportunities

Surveys by the National Milk Harvesting Centre show that milk cooling accounts for approximately 30% of the total energy costs of operating a dairy, so designing and operating an efficient milk cooling system can significantly reduce energy demand and shed operating costs (NMHC, 2006d). DX systems are the simplest and most energy efficient way of cooling milk, (NMHC, 2006e), however other issues such as vat fatigue where vats fracture and leak refrigerant has resulted in greater acceptance and penetration of indirect cooling systems with packaged chillers. The greatest energy saving opportunities with MV systems are with pre-chillers, heat recovery systems and improved maintenance practices.

8.3.1 Pre-chillers

Plate heat exchangers that use bore or surface water to remove heat and pre-cool milk from 34°C to around 25°C are used on most farms as they are the simplest and most cost effective means of pre-chilling.

The performance of plate heat exchangers in the field varies significantly, as they are not always specified or applied correctly. Areas that can affect performance are as follows:

- Incorrect flow rate sizing; the water flow rate should exceed the maximum milk flow rate by at least 3 to 1;
- Sourcing the coldest water/cooling fluid all year round;
- Incorrect use of cross plate heat exchangers; need to ensure that the cooling fluid and milk are flowing in opposite directions; and
- Steady flow of milk to the plate heat exchanger; a steady flow of milk can be controlled more effectively with a variable speed drive (VSD) rather than a float switch and timer that sends higher volumes of milk in bursts. The low penetration of the use of VSD's in Australia can be explained by the long payback periods estimated to be in the order of 2.5 to 5 years depending on the daily milk volume and expected improvement in milk cooling efficiency (NMHC, 2006c).

Industry sources estimate that more than 25% of all indirect cooling systems sold today have double stage pre-coolers. If correctly designed, applied and maintained can deliver energy savings of up to 30% or more in dollars if off-peak cooling is used. A higher penetration of more sophisticated pre-chillers that are correctly sized and applied would deliver an energy saving of more than 10% or around 46 GWh per annum.

8.3.2 Heat recovery systems

A significant proportion of energy is consumed in heating water on dairy farms, with 41% reported by the National Milk Harvesting Centre in Australia and 30% reported in Cowshed case studies in New Zealand. The following technology provides two of the options available to reclaim heat from the refrigeration system (NMHC, 2006b):

- Plate heat exchanger built onto the condensing unit where heated water is stored in a boiler;
- Double walled heat exchanger integrated in a boiler;
- Heat pumps (Cowshed, 2007).

Both of these options store the recovered heat in a boiler that can be topped up with gas or electricity to the meet the desired hot water temperature of 80°C or more.

8.3.3 Maintenance

There are a variety of simple maintenance practices that can be undertaken to improve operational efficiencies of MV systems, they include:

- Cleaning dirty or blocked plate heat exchangers, which improves heat transfer efficiencies and minimizes associated losses;
- Blowing dust out of condenser coils can avoid unnecessary system run time due to inefficient heat rejection from clogged condenser coils;
- Tightening or replacing worn belts on traditional belt driven equipment can minimize belt slippage and mechanical transfer losses between the motor and compressor;
- Ensure the refrigeration system is 'critically charged' with an ideal amount of refrigerant to optimize system performance and avoid taking longer to achieve the desired pull down temperature;
- Optimizing control settings to ensure the thermostat switches the refrigeration system off when the desired milk temperature is achieved and the thermostatic expansion valve is correctly adjusted to optimize system performance; and
- Ensure the heat exchangers are operating as designed with both Milk and the working fluid running at prescribed flow rates in a cross flow direction and that the working fluid has the correct chemical composition.

The energy reduction opportunities associated with cleaning heat exchangers and condenser coils are quantified in a case study undertaken by the National Milk Harvesting Centre as follows:

> ***Maintenance eats away at energy bill (NMHC, 2006a)***
>
> *It took less than an hour for Tasmanian dairy farmer Brett Ford to save energy in his dairy, following CowTime's dairy energy savings checklist. It involved no direct cost, just simple maintenance of plant equipment and a review of cleaning processes.*
>
> *The first thing he did was measure the temperature difference on his plate heat exchanger and found the difference to be 12°C, a long way off the recommended 2°C difference. That was a clear sign the plate cooler wasn't working efficiently so he stripped it down and cleaned it. Brett also cleaned the dust from the vat's condenser a job he previously did about every 18 months but now plans to do twice a year.*
>
> *These two simple maintenance steps mean milk is cooled 15 minutes quicker after each milking, saving costly vat running time. The thermometers stay on the pipes, providing a regular reminder to monitor temperatures.*
>
> *The National Milk Harvesting Centre estimates that a 12°C temperature difference equates to wasting 4,887 kWh per annum or $733 based on $0.15 per kWh for a farm that produces 1 million litres of milk per annum.*

In summary the case study states that based on research conducted by SEAV and Bonlac, some farmers use up to four times the energy than others use to harvest the same amount of milk. The combination of pre-chillers, heat recovery systems, energy reduction education, benchmarking and improved maintenance practices could save more than 20% of all electricity consumed by a typical farm.

8.4 Review of Australian and International standards

The main regulatory issues in the MV industry are milk quality and safety. These primary concerns are reflected in the existing international standards that have little emphasis on energy efficiency.

The main international standards are:

- *EN13732/A2 (2008-06), Food processing machinery,* which covers bulk milk coolers on farms including construction, performance, suitability for use, safety and hygiene;
- *ISO 5708 1983, Refrigerated bulk milk tanks*, which specifies certain requirements for design, construction and performance of refrigerated tanks and related of tests. It does not deal with electrical or safety regulations;
- *Sanitary Standards 3A 13-10, 2003, Farm Milk Cooling and Holding Tanks*, which covers the sanitary aspects of tanks used to cool and store bulk milk on dairy farms;
- *AS 1187-1996: Farm milk cooling and storage systems,* which sets out minimum requirements for the design, construction and performance of bulk milk cooling and storage systems including the use of energy saving pre-coolers. The performance measures in the standard relate to milk cooling performance rather than energy reduction initiatives.

AS 1187-1996 is a voluntary standard that was originally prepared with contributions industry contributions from the Australian Dairy Authority Standards Committee, Australian Dairy Farmers Federation, Dairy Industry Association of Australia and the former Commercial Refrigeration Manufacturers Association.

8.5 Conclusions and recommendations

The market is transforming to more efficient commercial refrigeration equipment of its own accord, albeit at a modest pace. Most farms use plate heat exchangers used for pre-chilling and the penetration of more sophisticated pre-chilling techniques is increasing as a result of farm consolidation and acceptance of new technology.

The energy reduction opportunities discussed in section 8.3, including the use of pre-chillers, heat recovery systems, variable speed drives, energy reduction education, benchmarking and improved maintenance, are specialised to the industry. Therefore any further promotion of these opportunities needs to done in close cooperation with the relevant industry bodies with direct links to the dairy industry.

It should be noted that there have been several investigations and initiatives over previous years targeted at the diary industry, and some of the improvements in energy performance have undoubtedly resulted from these efforts. Further improvement appears to be hampered by a lack of investment caused through commercial uncertainty, rather than a lack of information or other barriers.

As a result, the main recommendations from this review are the policy measures applied across all compressors and to a lesser extent fan motors as they only exist on condensers. The difference between compressor technologies used in new equipment is in the order of 10%, which is likely to translate to reduction in energy consumption of around 5% over time.

It is still important to maintain a good level of activities promoting industry best practice, and it is recommended that mechanisms to develop and distribute well targeted information, including benchmarks, are investigated by responsible government agencies in consultation with the industry.

The use of incentives also warrants further investigation, since these will help to draw attention to the energy efficiency opportunities and require the development of a list of eligible technologies.

8.6 References

Aurora Energy (2007)	Fact Sheet, The Energy Efficient Dairy, Aurora Energy, 2007
Cowshed (2007)	Energy Efficiency in Dairy Sheds, Case Study: Mahana Blue heat pump at Glencairn, June 2007, available from www.cowshed.org.nz
Dairy Australia (2008)	Dairy Australia, Australian Dairy Industry In Focus, 2008
EC (2008)	Product Profile on Industrial Chillers prepared by Energy Consult for Sustainability Victoria, 2008
ES (2007)	Cold Hard Facts, prepared by Energy Strategies in association with Expert Group, 2007
Kyabram Dairy Centre (2002)	Managing Dairy Farm Costs, Kyabram Dairy Centre, July 2002
LIC, 2008	New Zealand Dairy Statistics 2007/08, prepared by Livestock Improvement Corporation, 2008
NMHC (2006a)	*Cow Time Case Study*, Maintenance eats away at energy bill, National Milk Harvesting Centre, 2006
NMHC (2006b)	*Cow Time Quick Note 3.4*, Dairy Energy Savings Checklist,

National Milk Harvesting Centre, 2006

NMHC (2006c) *Cow Time Quick Note 3.5*, Options to reduce your electricity usage, National Milk Harvesting Centre, 2006

NMHC (2006d) Cow Time Quick Note 4.6, How effective is your plate cooler, National Milk Harvesting Centre, 2006

NMHC (2006e) *Cow Time Quick Note 4.7*, Milk Cooling, National Milk Harvesting Centre, 2006

9 Beverage Cooling

Beverage cooling systems in Australia consume an estimated 400 GWh of electricity per annum, which is less than 3% of the total electricity used in Australia for commercial refrigeration. It is estimated that 115 GWh of this total is consumed by pumps circulating glycol in beer systems.

Beverages cooling systems are used to supply chilled beverages for consumption in all sorts of hospitality venues including pubs, clubs, hotels, large restaurants with bars and large entertainment venues such as sports and event stadiums. Beverages cooling discussed in this section excludes process refrigeration used in major breweries.

The chilling, dispensing and retailing of beverages in commercial venues is delivered with one of two types of equipment:

- Beer cooling systems that decant[29] beer from kegs, typically chilled by glycol cooling systems and poured from taps commonly referred to as fonts[30]. Smaller beer systems can be chilled with ice bank cooling systems, and
- Post-mix equipment that dispenses soft drinks, mixed beverages and wine chilled with ice bank cooling systems.

This section provides a description of the two types of beverage cooling equipment in common use, builds a market profile with estimates of electricity consumption of the equipment, and estimates greenhouse gas emissions resulting from the energy use. Horizontal measures involving efficiency improvements to components such as compressors, fan motors and pumps are the most cost-effective initiatives for this sector. Improvement opportunities with compressors and fans are discussed in Sections 3 and 4 respectively, and the industrial equipment review (SV, 2009) is likely to result in measures designed improve the efficiency of pumps and motors used in beverage cooling. These horizontal measures are expected to improve the stock of equipment by more than 10% over time.

9.1 Description of technology

9.1.1 Beer cooling systems

Beer cooling and decanting systems vary in size and configurations depending on the venue size, number of taps and variety of beers served.

Bulk liquid beer is supplied to venues by breweries in beer kegs that are pre-chilled in separate WICs or cellars to approximately 3°C to 5°C. The beer is pressurized with CO_2 to carbonate the beer and pressurise the beer lines enabling it to be poured. The beer is chilled by using a glycol solution which has been cooled in a refrigerated bath and is circulated with pumps around the insulated beer lines to ensure the beer is delivered to ideal Australian beer retailing temperatures of 2°C to 4°C. The glycol is circulated 24 hours a day to ensure the beer lines are constantly cooled and beer is always ready to pour.

Figure 111 shows a typical cooling circuit, beer reticulation system and taps to dispense beer in a small bar.

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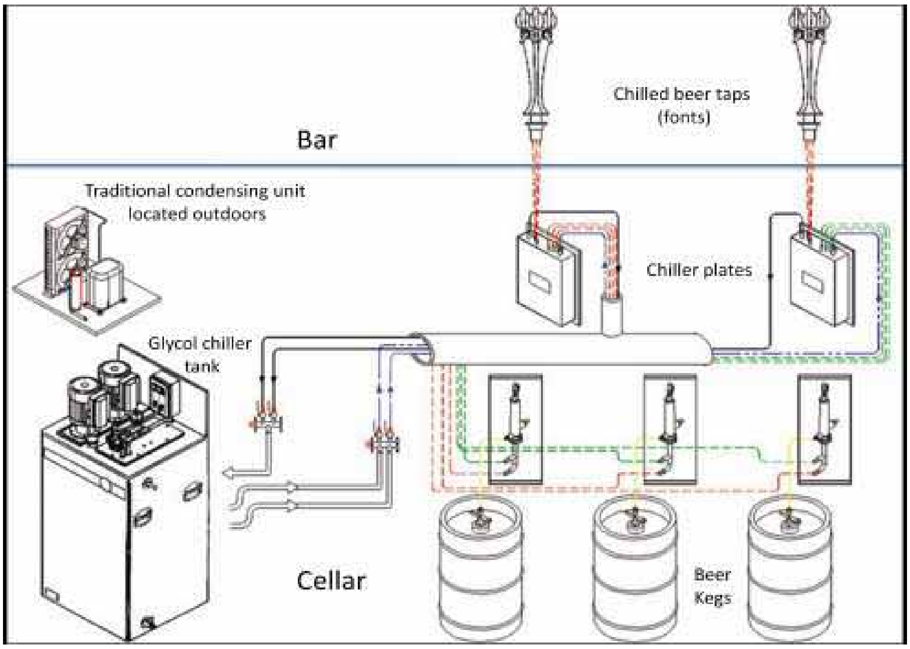
[29] Decanting is the process of pouring a liquid from one container to another and in some cases to separate out sediment. Decanting is terminology used in the beverage cooling industry to describe the transfer of beer from the keg.

[30] Beer dispensed from beer systems is commonly referred to as 'tap beer' (also known as draft beer) opposed to packaged beer supplied in bottles or cans.

Figure 111: Schematic diagram of beer cooling and dispensing system



(Source: Lancer Pacific)

A typical beer cooling system comprised the following main components, which are illustrated in Figure 112 to Figure 117:

- Glycol chiller tank with glycol circulating pumps and agitators;
- Chiller plates for close temperature control located under the bar near the taps, offered as 2, 4, 6 and 8 coil or single coil inline heat exchangers;
- Multiple pouring taps or fonts to offer consumers a choice of beers. The fonts are chilled, forming ice to increase consumer appeal, and
- Remote refrigeration condensing unit using R404A refrigerant piped up to the glycol chiller tank.

Figure 112: Glycol chiller tank

Figure 113: Packaged condensing unit

Figure 114: Traditional condensing unit

Figure 115: Chiller plates

Figure 116: Iced beer fonts

Figure 117: Iced beer fonts

(Source: Lancer Pacific; Bitzer Figure 3 and Heatcraft Figure 4)

The glycol tanks are offered in a range of capacity sizes to suit venue demand and consumer requirements, as shown in Table 48. Remote condensing units are matched to these capacities to provide refrigeration effect, where the coils in the glycol bank act as the evaporator to cool the secondary refrigerant (glycol). The condensing units can be packaged, as illustrated in Figure 113, or a traditional 'open style' see Figure 114 and are generally located outdoors. Smaller beer systems can have ice bank cooling systems similar to the unit shown in Figure 118 with a self-contained condensing unit up to around 3.5kW operating on R134a refrigerant.

Table 48: Nominal number of taps and refrigeration capacity by venue size

Venue size	Number of taps	Nom. refrigeration capacity (kWr)
Small	4 to 6	1.5
Medium	12 to 18	8
Large	30 to 40	15
Extra large	Up to 200[31]	75

Product presentation of draught beer at the bar is very important to beverage retailers and publicans. Ideal Australian beer retailing temperatures are from 2°C to 4°C and beer systems are expected to pour a perfect beer, resulting in a full flavoured product with appealing head (beer foam) retention. Ice formation on the beer fonts is also important to beer presentation. In most situations, glycol between -2°C to -3.5°C flows through the font causing moisture in the air to condense, which then freezes because the glycol flowing within the font has a lower freezing point than water. Figure 117 illustrates this effect of ice build up on the font.

9.1.2 Post-mix equipment

A post-mix machine transforms the concentrated syrup flavouring to a drinkable beverage by mixing it with chilled water and with CO_2 for carbonated drinks.

Beverage syrup is typically supplied in 'bag-in-box' casks and syrup lines run from the casks to an ice bank cooler. Each line feeds into an individual stainless steel coil for that beverage. The cooler has a refrigeration system that is used to chill a tank of water. Inside the cooler there are copper refrigerant

[31] Extra large venues with are large entertainment venues such as sports and event stadiums. For example, Melbourne Cricket Ground has over 60 taps including 4 automatic taps that fills several cups at a time.

pipes that are immersed in a water bath. From these coolers the beverage runs through 'pythons' (insulated gangs of flexible beverage hose) through which chilled water or soda water is pumped in a closed circuit system to provide cooling.

The systems are often referred to as Ice Bank machines; this is because the copper refrigeration pipes in the tank build up a layer of ice in the water bath and the ice provides a thermal bank of cooling when heavy beverage pouring demand occurs, and allows the refrigeration system to have some built up cooling capacity.

Post-mix systems vary in capacity (200 to 950 litres per hour or more) and number of drink varieties (up to 14 from one dispenser).

The main components of a typical post-mix arrangement are as follows:

- Ice Bank Cooling tank complete with self contained condensing unit operating on R134a refrigerant;
- Insulated python piping assembly;
- CO_2 driven syrup pump;
- Carbonator supplied with water and bottled CO_2; and
- Post-mix dispensing unit or tap.

Figure 118 to Figure 121 provide illustrations of the main components that make up post mix machines, and Figure 122 provides an illustration of a soft drink dispenser typically found in fast food franchises.

Figure 118: Soft drink or wine dispenser

Figure 119: Ice bank cooling unit

Figure 120: Carbonator assembly and pump

Figure 121: Python and tube

Figure 122: Soft drink dispenser

(Source: Lancer Pacific)

The ice bank and refrigeration unit are generally only offered in two sizes based upon the beverage inlet temperature and the volume of beverage to be poured per hour. Table 49 provides typical capacities and operating conditions.

Table 49: Nominal sizes of post mix ice bank equipment

Unit size	Beverage inlet temperature (°C)	Beverage outlet temperature (°C)	Nom. capacity (Litres per hour)
Small	8	2.5	280
	24	3	200
Large	8	2.5	470
	24	3	950

The insulated python piping assembly is offered in 5 combinations of tube numbers, (4, 8, 12, 14 and 16) and with options of 19mm, 25mm and 32mm thick insulation.

Post-mix dispensing units are offered for a wide variety of carbonated or non-carbonated beverages in 5, 6, 7, 8, 10, 12 and 14 outlet assemblies, and are often branded for various products being sold. Contractors that specialize in beverage systems make up post mix assemblies from these components.

9.2 Market profile

Beverages cooling systems are used to supply chilled beverages for consumption in all sorts of hospitality venues including pubs, clubs, hotels, large restaurants with bars and large entertainment venues such as sports and event stadiums. The numbers of venues where most beverage cooling systems can be found is listed in Table 50 below[32].

Table 50: Number of commercial venues in Australia, 2009

Type of venues	Number of venues
Restaurants	15,142
Hotels/motels	9,132
Clubs	4,203
Function centres	832
Major venues/stadiums	50
Total	**29,359**

The number of venues that have beer systems is significantly less than the national statistics listed above since packaged beverages supplied in bottles and cans is more convenient for smaller venues with lower demand for beverages. The Australian Hotels Association and its state counterparts is the peak industry body for the hotel industry, claiming they represent approximately 80% of 6,807 hotels Australia wide (AHA, 2008). All of these venues will have one or more beer cooling systems.

[32] Estimates for the number of restaurants, hotels, clubs and function centres were based on a compilation of data from SV, 2009, ABS 8165.0, 2006 and ES, 2007. This data excludes 'non-employing' enterprises as they are less likely to have beverage cooling equipment. All data was adjusted with 1.5% growth per annum to harmonize 2009 estimates.

Most restaurants don't have the beer demand to justify the capital investment in a beer cooling systems and packaged beer offers a wide variety of choices for patrons. Large restaurants are more likely to have a post-mix machine as they offer a wide variety of mixed drinks, are less expensive and allow beverages to be sold at higher profit margins. Post-mix machines are commonly found in fast food franchises such as McDonalds and Hungry Jacks. This equipment is generally owned by the dealer and typically uses branded syrup from Coca-Cola Amatil (CCA) or Schweppes-Pepsi Cola.

9.2.1 Beer cooling systems

The number of new systems installed per annum is around 1,000 units per annum or 9% of the installed base. The average life-span of glycol cooling systems is around 13 years with the replacement of traditional Temprite instantaneous draft beer systems continuing to keep sales high[33]. The number of venues with beer cooling systems is estimated to be 9,000 small to large sized venues, plus an additional 50 major events venues, giving an estimated total of 11,450 dispensing systems nation-wide, as shown in Table 51.

Table 51: Number of venues with beer systems in Australia, 2008

Size of venue	Number of venues	Proportion of venues	Existing stock
Small	3,000	33%	3,000
Medium	4,000	44%	4,000
Large	2,000	22%	4,000
Major venue	50	< 1%	450
Total	**9,050**		**11,450**

The major suppliers of glycol beer cooling systems in Australia are:

- Hoshizaki Lancer;
- Andale;
- Bracton (was Allied Beverage), and
- IMI Cornelius.

These suppliers generally assemble the equipment locally to suit specialist local market needs and import accessories such as taps and fittings. Condensing units are generally sourced from local refrigeration wholesalers such as Bitzer, Heatcraft or Actrol and specialist accredited beer plumbers generally install and commission the equipment.

9.2.2 Post-mix equipment

The number of new systems installed per annum is around 1,600 units, or 5% of the installed base. The major suppliers of ice bank cooling systems in Australia are Hoshizaki Lancer and IMI Cornelius. They estimate the average life-span to be similar to a glycol cooling system, i.e. around 13 years.

[33] The most common beer cooling systems in Australia in the 1980s and 1990s was the Temprite instantaneous beverage cooler that was designed to pour high volumes of draft beer and was available in 2, 3 and 4 tap models. The Temprite was progressively replaced glycol chiller technology and packaged beer driven by consumer demand for greater beverage variety.

More than 90% of post-mix systems are owned, installed and serviced by the two major beverage manufacturers, Coca-Cola Amatil (CCA) and Schweppes-Pepsi Cola. There are a small number of 'independent' operators that purchase syrup for use on their own equipment and have them installed by refrigeration contractors and specialist beverage plumbers. The existing stock of post-mix equipment is estimated to be 33,000 units and is detailed in Table 52.

Table 52: Number and size of post-mix systems in Australia, 2008

Unit rating (kWr)	Proportion of sizes	Existing stock
≤0.5	5%	1,650
0.5 to 1.5	70%	23,100
1.5 to 3.0	25%	8,250
Total		**33,000**

CCA control an estimated 75% the post-mix beverage market, followed by Schweppes with a 20% share. The balance of the market of approximately 5% is spread across small independent suppliers. CCA forecasts achieved 3.8% growth in revenue in 2008 and forecast around 4% growth for 2009 (CCA, 2008). They expect to grow market share and sales volume by adding new products such as low carbohydrate and alcoholic beverages. The strong market position of the two major players should see continued growth of equipment at an annual rate of 4 to 5% per annum.

9.3 Energy consumption and greenhouse gas emissions

The energy consumed in beer cooling in commercial venues is split into two components, the energy to operate the glycol cooling unit and the energy to pump and circulate the solution from the tank to where the beer is poured. The glycol cooling unit operates 12 hours per day, six days per week in most venues except large event venues that may only operate 30 days per year. However, the circulation pumps generally operate 24 hours per day, all year round. Table 53 shows the estimated energy consumption and emissions from both components of beer cooling.

Table 53: Electricity consumption and emissions from beers systems, 2008

Equipment type	Proportion of total	Electricity Consumption (GWh p.a.)	Emissions ktCO_2-e
Glycol cooling	48%	109	109
Circulation pump	52%	115	116
Total	**100%**	**224**	**225**

The energy consumed by post-mix ice bank cooling systems to dispense beverages in commercial venues is estimated to be less than 200 GWh per annum. The refrigeration condensing unit consumes 65 to 70% of electricity with the agitator motor and carbonator pumps accounting for the balance. Table 54 shows the estimated energy consumption and emissions for the existing stocks of common size post mix machines. The calculations were based on equipment operating an average of 10 hours per day, all year round.

Table 54: Electricity consumption and emissions from post-mix equipment, 2008

Unit rating (kWr)	Proportion of total	Electricity Consumption (GWh p.a.)	Emissions kt CO_2-e
≤0.5	3%	5	5
0.5 to 1.5	57%	102	103
1.5 to 3.0	41%	73	73
Total	**100%**	**180**	**180**

The Greenhouse gas emission factor used to calculate emissions was 1.007 Kg CO_2-e/kWh, which is a weighted average (based on state population) of the NGERS state based full fuel cycle indirect emission factors for consumption of purchased electricity from the grid (DCC, 2008).

9.4 Opportunities for energy reduction

There is limited research material available on energy reduction opportunities for beverage cooling equipment. The main energy reduction opportunities with beverage cooling systems are with components rather than systems including;

- Compressors;
- Fan assemblies on condensing units;
- Motors driving pumps and agitators, and
- Insulation on pipes.

Since these components consume the majority of the electricity in beverage cooling systems, improving the efficiencies of these components will lead to overall system improvements. Keeping the length of the pipe run between the glycol tank and point of pouring on beer cooling systems is an obvious way of keeping losses to a minimum; however building constraints and new building designs that position cellars for aesthetic reasons or to maximize bar space rather than energy conservation sometimes makes it difficult to avoid. Increasing the distance between the cellar and the point of pouring has the effect of increasing the size of the condensing unit required to refrigerate the glycol, which results in greater energy consumption.

'Green consumerism' is encouraging major beverage companies such as CCA to be seen as more 'environmentally friendly' by adopting more sustainable practices[34]. To date most of the international press has focused on adopting alternative refrigerants on refrigerated display cases with little or no input into energy reduction initiatives on post-mix equipment. This is likely to be a result of the split incentives between the major beverage retailers and venue operators where the beverage retailers that own and supply the equipment have no incentive to reduce running costs and energy consumption.

[34] 'Green consumerism' is a form of ethical consumerism where green brands that identify themselves as ethical, has led to a rise in ethic-based decision making and consumer mass marketing.

9.5 Australian standards

There are no Australian Standards for beverage cooling equipment or any related standards that consider energy efficiency of these devices. Beer suppliers have product specifications to pour perfect beer and beverage suppliers, such as CCA, have pull-down guidelines to ensure product quality is maintained. None of these product standards relate to energy efficiency.

The main standard in use in the beverage industry is *AS 5034-2005; Installation and use of inert gases for beverage dispensing.* This standard specifies the requirements for the design, location and installation, testing, commissioning, safe use and maintenance of the compressed inert gas or refrigerated liquid equipment and reticulated and portable systems necessary to dispense beverages. This voluntary standard is accompanied with *B 001-2007; Gas leak testing solution logbook*, which provides a provides a methodology and recording system for the implementation of the weekly leak checks and 6-monthly and 12-monthly maintenance procedures that are required by *AS 5034-2005*. This standard has no energy reduction initiatives.

9.6 Overseas policies and standards

No international energy efficiency agencies or regulators have currently implemented energy efficiency policies targeted towards beer cooling or post-mix equipment. Current policies in Europe and the UK are focusing on improving the energy efficiency of compressors and fan motors. Two standards worth noting are:

- *British Standard PAS 57:2003, Cellar cooling equipment*; procedure for determining performance and calculating energy efficiency, and
- *ANSI/ASHRAE 32.2-2003 (RA2007); Methods of testing for rating pre-mix and post-mix beverage dispensing equipment*. This standard establishes uniform methods of testing for determining laboratory performance of pre-mix and post-mix non-frozen beverage dispensers that are self-contained, counter mounted, electrically powered, and mechanically refrigerated and that incorporate a water-bath or dry-block reservoir.

9.7 Recommendations

The main energy saving contributions from this class of equipment will come from horizontal measures introduced on commercial refrigeration and industrial equipment components. The following is a summary of recommended actions from that would reduce energy used by commercial venues with beverage cooling systems.

- Minimum energy performance standards (MEPS) are proposed for all compressors offered for sale in Australia and New Zealand with a displacement between 1.4 to 836m^3/hr. This measure is likely to take effect towards the end of 2012, which allows for a reasonable adjustment period for suppliers and customers and will improve the performance of compressors on new condensing units installed to service beverage cooling equipment and replacement compressors for existing equipment. For more detail refer to Section 3:
- Minimum energy performance standards (MEPS) are proposed for all fan motors used in non-domestic refrigeration, offered for sale in Australia and New Zealand with sizes ranging from 5 to 2,000W. For more detail refer to Section 4;
- The review to improve energy efficiency of Industrial Equipment includes pumps used in commercial buildings from 0.75 to 750kW, which covers most glycol pumps used in beverage cooling systems

that are typically 1.5 to 3.0kW. The Industrial Equipment review is still in progress and proposes to investigate opportunities with motor and pumping efficiency. For further detail refer to the final recommendations from the Industrial Equipment review (SV, 2009);

- These horizontal measures are expected to improve the stock of equipment by more than 10% over time.

9.8 References

ABS 8165.0, 2006	Counts of Australian Businesses, Australian Bureau of Statistics, 2006
AHA, 2008	Key Industry Facts, Australian Hotels Association, 2008
ANSI/ASHRAE 32.2-2003	ANSI/ASHRAE 32.2-2003 (RA2007); Methods of testing for rating pre-mix and post-mix beverage dispensing equipment
AS 5034-2005	Australian Standard, Installation and use of inert gases for beverage dispensing
BS PAS 57:2003	Cellar cooling equipment; procedure for determining performance and calculating energy efficiency, British Standards, 2003
CCA, 2008	Coca-Cola Amatil, 2008 Annual Report, 2008
DCC, 2008	Department of Climate Change, National Greenhouse Accounts (NGA) Factors published 2008
SV, 2009	Improving Energy Efficiency of Industrial Equipment, prepared for Sustainability Victoria, 2009
SV, 2008	Catering Equipment Study, Sustainability Victoria, 2008

10 Mobile Refrigeration

10.1 Description of technology

The majority of mobile refrigeration is either, road-based, commonly referred to as transport refrigeration, or "marine", which is primarily located on fishing vessels. Transport refrigeration technology is made up of transport refrigeration units (TRUs) and off-engine vehicle powered units that refrigerate containers, whilst fishing vessels contain specialized chilling and blast freezing equipment.

Refrigerated shipping containers, commonly known as "Reefers", have been excluded from this report. They are not considered part of the Australian or New Zealand rolling stock of refrigerated transport as they are generally specified, owned and controlled by overseas operations. "Reefers" enter Australian and New Zealand shipping ports where they may travel inland to dispatch refrigerated goods and are occasionally serviced or repaired by specialized service companies such as International Reefer Services prior to departure[35].

10.1.1 Transport refrigeration units (TRUs)

TRUs are refrigeration systems powered by dedicated diesel internal combustion engines designed to refrigerate fresh and frozen[36] perishable products that are transported on semi-trailers, truck vans and rail cars. Figure 123 provides an illustration of a TRU without its housing skin; note the engine is shown on the lower right hand side and the refrigeration unit on the lower left hand side. Off-engine refrigeration units depicted in Figure 124 are smaller vehicle powered refrigeration units where the refrigeration compressor is belt-driven off the vehicle's engine. Off-engine units are commonly used on small rigid body trucks and delivery vans with optional electrical stand-by.

Figure 123: TRU with housing skin removed

[35] Aust Bureau of Statistics estimates that 3% of containers are refrigerated based on tonnage moved p.a.; and 93% of the total refrigerated load comprised food, based on tonne-kilometres travelled (ABS, 2002).
[36] Fresh is typically classed as 2°C and frozen -20°C.

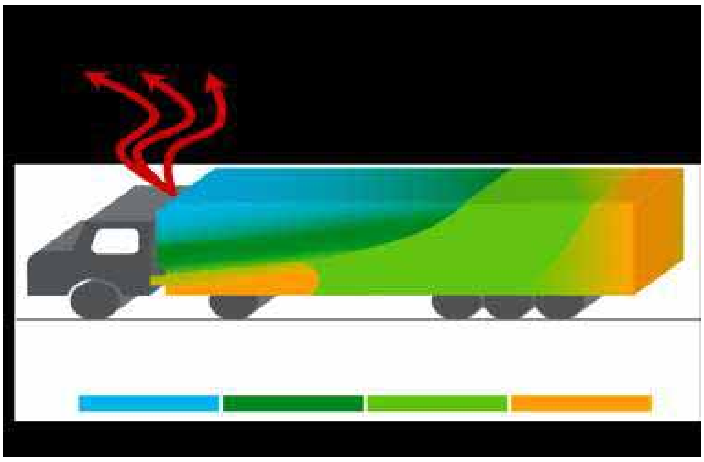
Figure 124: Vehicle powered unit

The purpose and operation of a transport refrigeration system is similar in principal to a stationary cool room - it is designed to refrigerate and protect its contents by removing heat from the load space at a rate equal to or faster than it is replaced. The cold storage area can be medium temperature, low temperature or a combination achieved with a partition and two evaporators.

Figure 125 provides an illustration of the heat distribution of the frozen goods compartment of a truck. The blue zone in the diagram represents the cold air blown from the evaporator that gradually warms as it travels towards the end of the compartment. Heat is picked up in the air stream and is circulated to the front where it is rejected outside via the condenser. Effective temperature management of the storage area is critical as in some instances small variations in temperature can significantly affect the shelf-life of sensitive produce. For example, a difference of 1°C can reduce the shelf-life of lettuce by over a day.

Effective control of the temperature distribution is dependent on both sufficient cooling capacity and air distribution; therefore the evaporator must have enough air volume and velocity to effectively circulate cold air throughout the compartment. In demanding applications, systems need to be designed with sufficiency capacity to provide rapid temperature recovery caused by loss of refrigerated air due to extended door openings.

Figure 125: Temperature pattern and heat rejection of a transport refrigeration system



Fuel consumption is a significant expense in the transport industry and is a key driver of truck technology. Therefore dollars-per-hour-per-annum is a more common industry measure of performance than the coefficient of performance of the refrigeration unit. The fuel consumption of truck (as a result of refrigeration) can vary significantly from 1.8 to 6 litres per hour, depending on a variety of factors such as capacity, set point temperature, produce, outside ambient temperature and insulation type or thickness.

The refrigerated storage area or structure vary in size, quality, construction and use, however the insulation value surrounding the refrigerated space is the most significant factor in determining thermal losses in land based refrigeration transport. The insulation specification on trucks can vary from 38 mm PIR to single layer curtains with no insulation.

It is estimated that mobile refrigeration systems in Australia and New Zealand can produce up to 30% more emissions compared to overseas counterparts, mainly due to lower insulation levels used. Australian and New Zealand rigid body truck container manufacturers are unable to produce bodies to the same K values as Europe since the maximum width of trucks in Australia and New Zealand is limited to 2.5 m, compared to 2.6 m in Europe and the USA. Table 55 provides a summary of typical refrigeration load examples for a 13.7 m long storage area on 2.5 m and 2.6 m wide vehicles. These examples show the theoretical refrigeration load and the increased load in practice caused by thermal bridges necessary to strengthen thin wall construction. Industry specialists claim these thermal bridges increase the theoretical refrigeration load by 1.6. These examples show the potential to improve energy performance by more than 36% and were presented by industry to the Department of Transport and Regional Services in 2001.

Table 55: Refrigeration loads of 13.7 m long refrigerated storage area on a 2.5 m and 2.6 m wide vehicle

	Refrigeration load	
	Theory	Practice
2.5 m wide vehicle with 38 mm thick walls	4.2 kWr	6.7 kWr
2.6 m wide vehicle with 88 mm thick walls	2.7 kWr	<4.3 kWr
Reduction in capacity	36%	>36%

Figure 126 provides a floor plan with standard pallet sizes and clearances, which shows why a 2.5 m limit allows only 38 mm insulation on the container walls. The major impediment to increasing the maximum truck width appears to be the narrowness of existing road and built environment infrastructure.

Figure 126: Floor plan of container and maximum allowable insulation thickness

10.1.2 Fishing vessels

Fishing applications have extreme refrigeration load conditions due to on-board blast freezing and the harsh environments in which they operate in (corrosion/shock vibration/oil level issues/rough seas). As a result they require robust equipment designs. The larger vessels have an onboard catch processing facility (see Figure 127) with refrigeration design loads similar to land based designs, however the equipment is very specialized (see below).

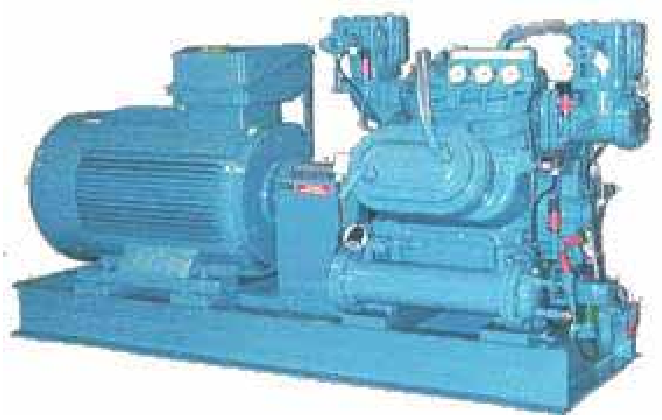
Figure 127: On board processing facility

The refrigeration systems have gone through a few generations of change from old belt drive systems (operating on CFC drop-in replacement refrigerants) to two stage systems operating on R22 and more recently systems operating on HFCs. The majority of the existing stock of condensing units is open drive (or hybrid open/semi) with leaky shaft seals. Recently there has been a shift towards more efficient semi-hermetic compressors with less risk of refrigerant leaks, however not many systems have been installed as the fishing industry is facing a number of commercial pressures and is shrinking rapidly.

A modern 15 to 20 meter vessel may consist of three 20hp semi-hermetic compressors running from diesel generator sets which service two blast freezers (see Figure 128) and a hold container. Each blast freezer is designed to pull-down 1,000 kg or more of seafood each from around 19^{o}C to -30^{o}C in as little as 12 hours and a hold (5 x 6 x 2.4m high) can take 10,000 kg of seafood down to -25^{o}C. The evaporator coils are purpose built with copper fins and condensers, often shell and tube type, designed for marine applications. The rack systems are compact in design to fit inside hulls of vessels, as illustrated in Figure 129 below.

Figure 128: Blast freezer

Figure 129: Compact basic rack system



The fuel consumption of fishing vessels varies significantly depending on the length of vessel, type of catch, length of season, age of vessel and the hours logged per annum. Deep sea fishing vessels can log 4,000 hours per annum while smaller boats with planing hulls may only fish for 1,500 per annum and have minimal refrigeration requirements. The vessel's power and refrigeration is driven by auxiliary generator sets that can range from units capable of consuming 15 to 54 litres of diesel per hour or more on large vessels.

10.2 Market and emission profile

The two main mobile refrigeration application segments in Australia are truck refrigeration and fishing trawlers generating an estimated 127 kt CO_2-e and 98 kt CO_2-e of emissions per annum respectively. Truck refrigeration emissions can be dissected into "inter-modal" (commonly known as road trailers) with 83 kt CO_2-e, "diesel drive" with 26 kt CO_2-e and "off engine" with 18 kt CO_2-e.

10.2.1 Truck refrigeration

A total of 6,206 million litres of diesel was used by articulated and rigid trucks in 2007, which equates to 66.2% of all diesel consumed in Australian in that year. Light commercial vehicles used 1,687 million litres, equivalent to a further 18.0% of all diesel consumed (ABS, 2008). Truck refrigeration systems are responsible for between 70-90 million litres of diesel, equivalent to 5% of the total consumption in Australia.

Truck refrigeration technology is dominated by two international companies (Carrier Transicold and Thermoking) using equipment sourced from either European or US markets. The key customers and stakeholders that have influence over technology decisions, maintenance practices and food safety are the major food retailers (Coles, Woolworths, Aldi and Metcash) and cold logistics companies (Toll Group, Linfox, Lindsay Bros and potentially Woolworths). The peak industry body for this segment and cold storage is the Refrigerated Warehouse and Transport Association of Australia Ltd (RWTA).

This application segment has a rolling stock of more than 20,000 units that operate between 2,000 and 4,000 hours per annum. The number of hours has declined since the introduction of the chain of responsibility guidelines to minimize delays and the use of TRUs as storage buffers. The key product categories, typical applications and nominal capacities are described in Table 56 below.

Table 56: Stock of truck refrigeration units by technology and application

Market Description	Technology	Application	Av. Capacity (1)	Existing Stock
Trailer & Inter-Modal	Transport Refrigeration Units	Articulated Trailers up to 48ft	18kW	4,300
Diesel Drive		Rigid Market 3 to 8 ton Trucks (6 to 18 Pallet)	4kW to 10kW	3,500
Off Engine	Vehicle Powered (Option Electrical Stand-by)	1 to 4 ton Trucks	1kW to 5kW	13,350
Total				**21,150**

(1) kWr rated at 2°C

10.2.2 Fishing vessels

The fleet of fishing trawlers consists of approximately 2,000 vessels ranging from 10 to 80 meters in length, although more than 75% of fishing vessels range between 10 to 20 meters according to registrations with the Australian Maritime Safety Authority. Some companies such as Raptis have fleets of 20 or more vessels however most vessels are controlled by small family businesses.

Specialized contractors supply and service the majority of refrigeration equipment to the fishing industry and Bock compressors gained significant market share when they were heavily marketed to the industry approximately 10 years ago. Other compressor suppliers include Bitzer, Grasso and Copeland, while re-build compressors are also popular (such as Frascold, Comef, Kelvinator, Terry) due to financial constraints.

There is very little investment in new or existing technology in the fishing industry. Consequently there is more scope for emission reduction through improved refrigerant containment practices with existing equipment than to transform the industry to higher efficiency technology.

10.3 Review of relevant codes, standards and regulations

The key issues driving standards and regulations in mobile refrigeration are perishable product safety, diesel emissions and refrigeration equipment standards. Product safety is likely to play a vital role in any new standards as temperature mapping of refrigerated products, including pharmaceuticals, is becoming vital. This means that governments departments such as the Food Safety Authority; Department of Transportation and Therapeutic Goods Administration have an interest in this industry as well as energy efficiency regulators.

10.3.1 Australian standards

Several years ago the Australian refrigerated transport industry established an emission reduction task force, which developed a voluntary standard, AS 4982-2003: "*Thermal performance of refrigerated transport equipment, specification and testing*". It covers key thermal tests that provide information about the insulation effectiveness and performance of the refrigeration plant. The standard closely follows the ATP Agreement in Europe for transport of perishables and the ISO standard 1496-2:1996(E) for freight containers. Nevertheless, compliance with the Australian standard is voluntary; no laboratory currently has the necessary accreditation to perform the tests outlined by the standard and there are currently no procedures to gain such accreditation. Consequently the standard has been largely ineffective and the main achievement of the task force has been the elimination of flared joints to minimise direct emissions.

10.3.2 Vehicle emission regulations in California

In January 2009 the US Environmental Protection Agency (EPA) granted the California Air Resources Board (CARB) authorisation to enforce the TRU Airborne Toxic Control Measure (ATCM). These measures follow the US EPA Tier 4 non-road engine Particulate Matter (PM) emission standards and apply to new and existing trucks in California.

The initial performance standards for 'in-use' TRUs are outlined in the table below, with more stringent levels due to come into force in 2015/16.

The standard can be met by:

- Using an engine that is certified to the Tier 4 diesel PM emission level;
- Equipping the existing engine with the appropriate level of verified diesel emissions control system (VDECS);
- Using 'alternative technology'[37] that eliminates TRU diesel engine operation (and emissions) while at a facility.

The CARB administer a compliance registration program linked to truck identification numbers and claim that PM emission factors for TRUs will be reduced by 92% in 2020[38]. For more details regarding ATCM and US EPA non-road engine PM emission standards see Attachment 6. In Europe transport refrigeration emissions are regulated by Stage IIIA of EU Directive 97/68/EC[39] where PM must be less than 0.60 g/kW/hr, which is not as stringent as US regulations.

Table 57: US EPA Tier 4 non-road engine PM performance standards

Category	Size	PM performance standards	
		g/hp-hr	g/kW-hr[40]
Low emission	<25 hp (18.6 kW)	0.3	0.40
Ultra low emission		n.a.	n.a.
Low emission	≥25 and < 50 hp (≥18.6 and <37.3 kW)	0.22	0.30
Ultra low emission		0.02	0.03

[37] 'Alternative technologies' include electrification, cryogenic refrigeration systems, alternative fuel systems, exclusive use of alternative diesel fuel, fuel cell-powered refrigeration systems, and other technologies that eliminate diesel engine PM emissions while at a facility.

[38] In 2004 the CARB claimed that particulate matter emission factors for TRUs would be reduced by approximately 65% in 2010 and 92% in 2020. The timing of the forecasts will be affected by the delayed in introduction and enforcement of the regulations.

[39] Note this appears to be a general standard applicable to various transport applications

[40] Converted to g/kW-hr by dividing g/hp-hr by 0.7457.

10.4 Conclusions and recommendations

Significant energy reductions of 30% or more are available from improved thermal insulation of the refrigerated rolling stock. One option is to increase the maximum width of trucks to 2.6m in line with many other countries; however this will require further investigation by the relevant government agencies and industry. Other options for increasing the thermal performance of the rolling stock also need exploring.

Increasing truck widths alone may not be sufficient to change entrenched practices. We recommend the elimination of low grade or non-insulated refrigerated transport insulation by ensuring that new rolling stock has a minimum insulation of R3.9 m^2K/W. Further measures could be explored to increase the turnover of the existing stock.

While it is possible that this could be achieved through a voluntary industry agreement, the proliferation of small operators in this market suggests that other policy mechanisms would be more effective. The use of regulations is likely to be more effective; however these products are currently beyond the scope of energy efficiency regulations for electrical and gas equipment.

Market based incentives applied to efficiency components, upgrades and new equipment, are also worthy of consideration. As an alternative to regulation, these are likely to be less effective for new stock (although this might depend upon the level of incentive) than regulations, however they could be complimentary and assist by stimulating the turnover of the existing stock to more energy efficient equipment.

In terms of the reduction of emissions resulting from the use of TRUs, the Californian Environmental Protection Agency ATCM regulation is the most stringent known policy measure which directly targets this equipment. Since much of the new equipment in Australia and New Zealand is sourced from product ranges supplied to European and US markets, there are benefits in ensuring that Australasian requirements are no less stringent than overseas markets. As a result a similar approach to that adopted overseas, and particularly in California, warrants further investigation in the light of on-going efforts to control vehicle emissions by regulators in Australian and New Zealand.

In the fishing industry, horizontal measures with improvements in compressor COPs will improve efficiencies of new and replacement equipment (excluding rebuild compressor replacements). Given the current financial status, low investment levels in the fishing fleet, lack of standards, complexity of equipment and relatively low emissions, it is difficult to justify further intervention in this sector.

In the mobile refrigeration segment, complimentary measures designed to increase the energy efficiency of the capital stock also warrant investigation. In particular, consideration should be given to the current levels of access by key stakeholders to information on the most efficient practices, components and equipment, and whether suitable mechanisms can be put in place to improve communication. One possibility is for the government and relevant industry associations to develop targeted information.

The key measures proposed for the mobile refrigeration sector are to further investigate with relevant government agencies and the industry the following:

- The design and use of materials to increase insulation capacity of refrigerated rolling stock to enhance benefits such as reduced fuel use, greater quality control of products and reduce risk of product spoilage.
- The feasibility of increasing the maximum permitted width of trucks to 2.6m to allow space for adequate insulation materials when standard pallets are used.
- Ensuring that new refrigerated transport products are insulated to a minimum of R3.9 m^2K/W. Investigate mechanisms such as regulation to achieve this.

- Specific incentives to encourage the uptake of practices that increase the energy efficiency of rolling stock and develop and promote targeted information on 'best practice' for this sector.
- The feasibility of putting in place emission standards for refrigeration transport systems similar to the US EPA Tier 4 non-road engine standards and the CARB in-use program.

10.5 References

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ABS (2002)	ABS9220.0 Freight Movements, Australia, Summary, 2002 (reissued)
AMSA (2006)	List of registered vessels, Australian Maritime Safety Authority
ATCM (2009)	CARB Airborne Toxic Control Measures, California State Non-road Engine and Vehicle Pollution Control Standards; Authorization of Transport Refrigeration Unit Engine Standards, see Federal Register of Environmental documents 2009
Californian EPA (2009)	Californian Environmental Protection Agency, Transport Refrigeration Unit Tutorial, 2009
Californian EPA (2004)	Californian Environmental Protection Agency, Fact Sheet, 2004
Cold Hard Facts (2007)	Cold Hard Facts; The Refrigeration & Air Conditioning Industry in Australia, prepared by Energy Strategies with association with Expert Group, for the Department of Environment, Heritage, Water & the Arts, June 2007
Commonwealth of Australia (2009)	National Strategy on Energy Efficiency, Council of Australian Governments (COAG), July 2009.

Attachment 6: CARB Airborne Toxic Control Measure (ATCM) regulations and US EPA Tier 4 non-road engine Particulate Matter (PM) emission standards.

Background:

In 1994 the Environmental Protection Agency (EPA) adopted the first set of emission standards "Tier 1" for all new non-road diesel engines greater than 37 kW (50 hp), except those used in locomotives and marine vessels. The Tier 1 standards were phased in for different engine sizes between 1996 and 2000, reducing emissions from nitrogen oxides (NOx) from these engines by 30 percent.

In 1998 the EPA adopted more stringent emission standards "Tier 2" and "Tier 3" for NOx, hydrocarbons (HC), and PM from new non-road diesel engines. This program includes the first set of standards for non-road diesel engines less than 37 kW (phasing in between 1999 and 2000), including marine engines in this size range. It also phases in more stringent "Tier 2" emission standards from 2001 to 2006 for all engine sizes and adds yet more stringent "Tier 3" standards for engines between 37 and 560 kW (50 and 750 hp) from 2006 to 2008.

In May 2004, as part of its Clean Diesel Programs the EPA finalized a comprehensive rule to reduce emissions from non-road diesel engines by integrating engine and fuel controls as a system to gain the greatest emission reductions. The new engine standards will reduce PM and NOx emissions by 90 percent. The outcome was the CARB Airborne Toxic Control Measure (ATCM) regulations for TRU diesel engines typically ranging from ranging from 7 to 27 kW (9 to 36 hp). They required TRUs to meet PM performance standards due to come into force on January 16, 2009. The EPA has approved a waiver where enforcement was delayed until July 17, 2009.

A full copy of the notice of decision is available on the US Federal Register 3030/ Vol. 74, No. 11/Friday, January 16, 2009/Notices, California State Non-road Engine and Vehicle Pollution Control Standards; Authorization of Transport Refrigeration Unit Engine Standards, Notice of Decision.

A summary is provided in this notice where they state the EPA today, pursuant to section 209(e) of the Clean Air Act (Act), 42 U.S.C. 7543(e), is granting California its request for authorization to enforce its Airborne Toxic Control measure (ATCM) establishing “in-use” emission performance standards for engines in transport refrigeration units (TRUs) and TRU generator sets that will be phased-in commencing in December 31, 2008.

Summary measures:

The Californian EPA Air Resources Board web site provides a wide range of information; the following summarizes a tutorial provided by the EPA to assist industry in understanding the new regulations.

A TRU is a refrigeration system that is powered by a diesel engine used to transport perishable goods. The EPA definition includes generator sets that provide electricity to electrically powered refrigeration systems for ocean-going shipping containers, which is outside the scope of this assignment. A refrigeration system where the refrigeration compressor is belt-driven off the vehicle’s engine is not classified as a TRU, which is described as “off-engine” in this study. Some other definitions include:

LETRU = Low emission TRU “in-use” performance standard

ULETRU = Ultra low emission TRU “in-use” performance standard

VDECS = Verified Diesel Emission Control Strategy, which are verified for specific engine models and model years

Alternative Technology = ULETRU (and LETRU) if diesel PM emissions are eliminated at distribution centres and limited at delivery point facilities.

There are two key parts to the regulation:

1. Facility reporting requirements, which was a onetime report that was due in 2006 applying to large distribution centres in California where TRUs operate under facility control;
2. Owner and operator reporting where "in-use" performance standards apply to all TRU engines that operate in California. Owners and operators of TRUs are responsible for compliance with the "in-use" standards as outlined in Table 58 and Table 59.

Table 58: US EPA Tier 4 non-road engine PM performance standards

Category	Size	PM performance standards		
		g/hp-hr	Alternative	g/kW-hr[41]
LETRU	<25 hp (18.6 kW)	0.3	Level 2 VEDCS retrofit	0.40
ULETRU		n.a.	Level 3 VEDCS retrofit or alternative technology	n.a.
LETRU	≥25 and < 50 hp (≥18.6 and <37.3 kW)	0.22	Level 2 VEDCS retrofit	0.30
ULETRU		0.02	Level 3 VEDCS retrofit or alternative technology	0.03

Table 59: US EPA compliance schedule for 'in-use" TRUs

Engine model year	Compliance standard date	
	LETRU	ULETRU
2001 and older	December 31, 2008	December 31, 2015
2002	December 31, 2009	December 31, 2016
2003	Does Not Apply	December 31, 2010
2004	Does Not Apply	December 31, 2011
2005	Does Not Apply	December 31, 2012
2006	Does Not Apply	December 31, 2013
2007	Does Not Apply	December 31, 2014
2008	Does Not Apply	December 31, 2015
2009	Does Not Apply	December 31, 2016
2010	Does Not Apply	December 31, 2017

[41] Converted to g/kW-hr by dividing g/hp-hr by 0.7457.

2011	Does Not Apply	December 31, 2018
2012	Does Not Apply	December 31, 2019
2013	Does Not Apply	December 31, 2020
2014	Does Not Apply	December 31, 2021

Compliance options for meeting "in-use" performance standards include:

- Replace "in-use" engine with new or newer engine, which only resets the compliance clock to the replacement engine model year plus 7 years;
- Replace "in-use" engine with a rebuilt/remanufactured engine that meets a cleaner certified emissions configuration;
- Retrofit with required level of VDECS;
- Use Alternative Technology, which must eliminate diesel engine emissions from the TRU engine at all facilities it visits, with narrow exceptions.

11 Data sources used in modelling

11.1 MEA modelling estimates

Modelling undertaken to estimate total energy consumption and greenhouse gas emissions, and the savings due to implementation of policy measures, is based on a variety of sources, many of which are discussed in the Background Technical Reports, Volumes 1 and 2 and referenced. These include data on the market penetration of technologies, average efficiency or performance levels and typical usage patterns.

The modelling also uses data from ***Cold Hard Facts***, published in 2007. In some cases this data has been corrected using more up-to-date or accurate information where available. ***Cold Hard Facts*** together with the source data is available from:
http://www.environment.gov.au/atmosphere/ozone/publications/cold-hard-facts.html

The initial background research for these reports was focused on the Australian market and therefore no bottom-up data has been collected at this stage for New Zealand. The energy consumption and greenhouse gas emissions for segments of the non-domestic refrigeration sector in New Zealand have been calculated on a pro-rata basis from the Australian estimates according to the relative populations of the two countries. The exception is milk vats, where the total energy consumption for this segment has been estimated based the quantity of milk produced in New Zealand and industry information on the energy intensity of milk production.

11.2 Greenhouse gas intensity

The following greenhouse gas coefficients have been used in order to calculate greenhouse gas emissions from electricity consumption in accordance with advice from E3.

Table 60: Electricity fuel cycle emission factors (t CO2-e/MWh delivered)

Year	Australia (1)	New Zealand (2)	Year	Australia	New Zealand
2005	-	0.6			
2006	1.036	0.6	**2016**	0.883	0.4
2007	1.021	0.6	**2017**	0.865	0.4
2008	1.007	0.6	**2018**	0.847	0.4
2009	0.993	0.6	**2019**	0.829	0.4
2010	0.980	0.6	**2020**	0.811	0.4
2011	0.964	0.6	**2021**	0.794	0.4
2012	0.948	0.4	**2022**	0.777	0.4
2013	0.932	0.4	**2023**	0.761	0.4
2014	0.916	0.4	**2024**	0.744	0.4
2015	0.901	0.4	**2025**	0.727	0.4

Source: http://naeeec.energyrating.com.au/reports/household-greenhouse.xls

(1) *Average fuel cycle emission factors (2) Marginal fuel cycle emission factors (updated 23/07/2009)*

11.3 Electricity tariffs

Unless stated, the consumer price of electricity is assumed to be AUD$0.16/kWh in Australia and NZD$0.1519/kWh in New Zealand, in accordance with advice from E3.