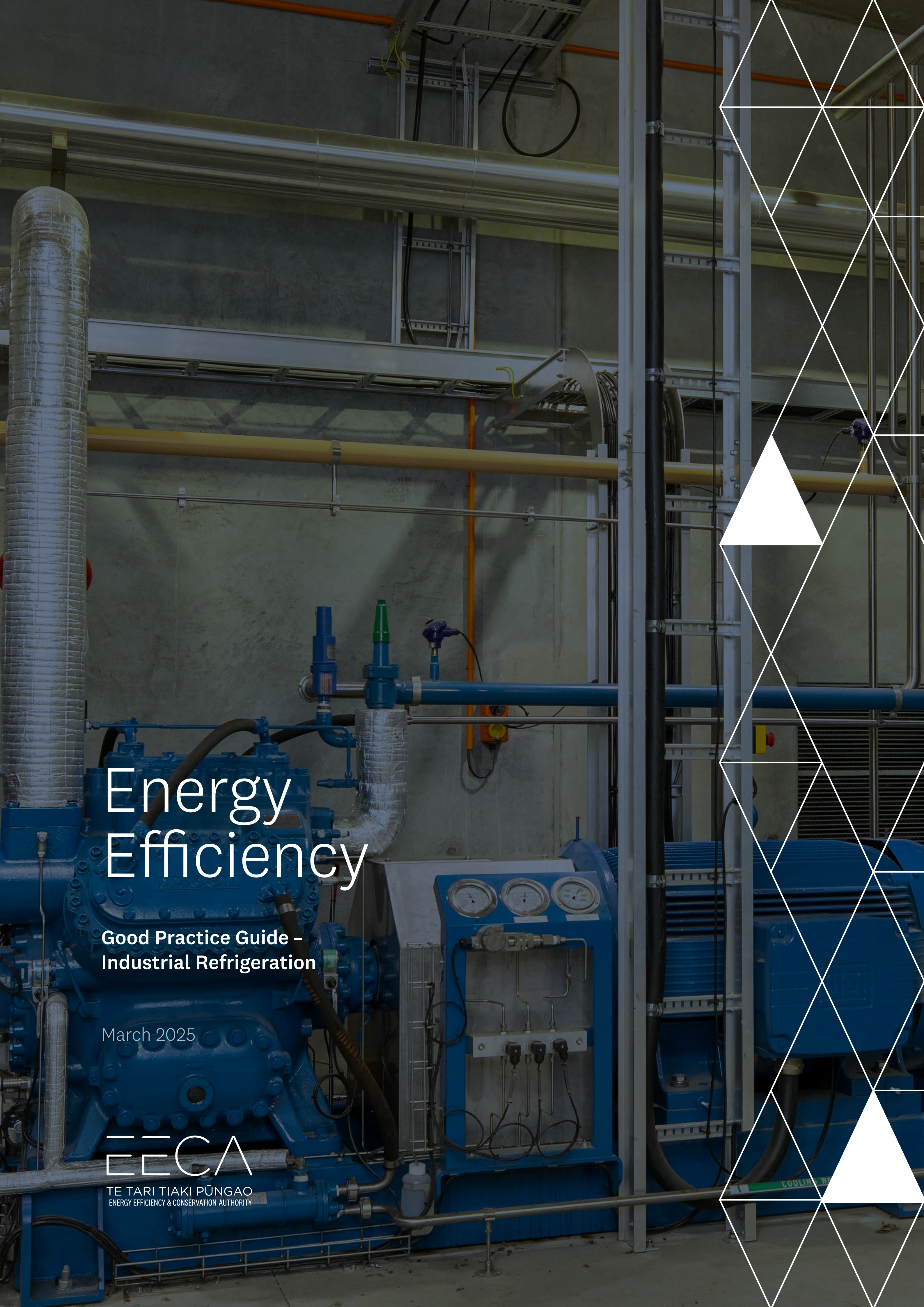

Energy Efficiency

Good Practice Guide – Industrial Refrigeration

March 2025

EECA
TE TARI TIAKI PŪNGAO
ENERGY EFFICIENCY & CONSERVATION AUTHORITY

For many businesses, refrigeration systems use large amounts of electricity, which significantly contributes to operating costs. Improvements to operating equipment have the potential to reduce energy use by up to 40%, whilst simple improvements in operational practices can reduce energy use by up to 20%.

This guide is aimed at refrigeration system operators and outlines system changes that can be made to improve the performance of equipment, reduce operating costs and improve profitability.

EECA would like to thank Dr Donald Cleland for his help updating this guide.

Contents

1 Introduction

This guide is aimed at helping improve the energy efficiency of medium to large-scale industrial refrigeration systems, such as cold stores and process chillers.   It provides 'good practice' information on system operation, and outlines several opportunities for improving your system's performance and efficiency, which will lead to benefits for your business.

By following this guide, you will be able to identify what changes can be made to improve the performance of equipment, reduce operating costs and improve environmental outcomes. The guide also covers using demand response and load-shifting to minimise peak demand energy costs.

The guide covers:

- Identifying your refrigeration needs and requirements, in terms of capacity, demand, time of use etc
- Identifying ways to upgrade and maximise the efficiency of your current system
- Identifying any needs for a new refrigeration plant or system
- Identifying ways to expand your existing system
- Next steps - What do I need to know in order to install a new system?

This guide has been developed to lead refrigeration operators through system changes; it is not intended to be a thorough technical guide or as a replacement for independent advice. Large scale pump circulation ammonia systems or controlled atmosphere (CA) storage of horticultural products are not considered in detail. References for more detailed technical information are provided along with links for additional information.

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Summary of efficient refrigerated facilities

Table 1 summaries the main opportunities for savings of energy identified throughout this guide. Whilst savings are not necessarily cumulative, the Table demonstrates the importance of whole-system approaches, which includes design, installation, operation, maintenance and periodic review. Table 1 also includes estimates of the magnitude of the potential savings and indications of their likely payback period.

Table 1: The key energy savings opportunities identified in this guide

Energy Savings Opportunity	Area of Application	Scope of Work	Potential Savings (typical/ maximum)	Likely Pay-Back Period
Thicker or better insulation	Refrigerated buildings & pipework	New assets Retrofit (piping only)	5/10%	Long
Rapid acting doors and enhanced door protection	Cold rooms & loadout areas	New assets Retrofit	10-15/30%	Medium
Minimise door open times	Cold rooms & loadout areas	Operations Controls	1/3%	Low
Energy efficient lighting & proximity controls	Cold rooms	New assets Retrofit	3-7/10%	Medium
Optimisation of defrost frequency and duration	Cold rooms & air-blast processes	Operations	5-10/20%	Low
Use of electronic rather than thermostatic expansion valves	Direct expansion systems	New assets Retrofit	5-10/20%	Medium
Flooded or pump circulation rather than direct expansion	Refrigeration system	New assets	5-10/15%	Long
Increased efficiency of fans/pumps, their motors & drives	Evaporators, condensers, compressors, refrigerant & coolant distribution systems, process equipment in cold rooms	New assets Retrofit	5-10/15%	Medium
Improved design of air flow and liquid flow circuits to reduce pressure drop	Process chillers & freezers Primary & secondary coolant distribution	New assets	5-10%/20%	Low

Energy Savings Opportunity	Area of Application	Scope of Work	Potential Savings (typical/ maximum)	Likely Pay-Back Period
VSDs on pump motors	Condensers Secondary coolant loops	New assets Retrofit	1-2/3%	Medium
VSDs on condenser fan motors	Condensers (especially if oversized condensers)	New assets Retrofit	2-3/5%	Medium
VSD on evaporator fan motors	Evaporators (especially if fan heat load is high)	New assets Retrofit	3-5/10%	Medium
VSD on compressor motors	Compressors (especially if often part-loaded	New assets Retrofit	5-10/20%	Medium
Raising evaporation temperature & suction pressure (e.g. reduced pressure drop, better controls, larger evaporators, improved evaporator performance)	All refrigeration systems	Retrofit Operations Controls Maintenance	2–3% for each °C (also similar cooling capacity increase)	Low/ Medium
Reducing condensing temperature & discharge (head) pressure (e.g. reduced pressure drop, better controls, larger condensers, improved condenser performance)	All refrigeration systems	Retrofit Operations Controls Maintenance	2–3% for each °C	Low/ Medium
Converting oil coolers from liquid injection to external heat exchangers	Screw compressors	New assets Retrofit	5/10% (also up to 5% increase in cooling capacity)	Medium
Use water-cooled or evaporative rather than air-cooled condensers	Condensers	New assets	5-10/15%	Long
Minimise static pressure drop due to liquid refrigerant “logging”	Suction line risers Condenser drain lines	New assets Retrofit Operations	0-5/10%	Low/ Medium
Optimal refrigerant selection	All refrigeration systems	New assets	0-5/10%	Long
Refrigerant system configuration enhancement e.g. multi-staging; economising	All refrigeration systems	New Assets Retrofit	5-15/25%	Long

Energy Savings Opportunity	Area of Application	Scope of Work	Potential Savings (typical/ maximum)	Likely Pay-Back Period
Improved control of compressors at part-load	Multi-compressor suctions	Operations Control	5-10/20%	Low
Optimal compressor selection	All refrigeration systems	New assets	5/10% (full load)	Medium
Heat recovery from oil coolers, desuperheaters & condensers	All refrigeration systems	New Assets Retrofit	5-10/20%	Long
Refrigeration system replacement if older than 10 years	All refrigeration systems	New Assets	20/40%	Long
Photovoltaic panel installation	Roofs of refrigerated buildings	New Assets Retrofit	Limited by roof area	Medium
Loading shifting	All refrigeration systems	Operations Controls	5-10/20% (costs savings)	Low/ medium
Change from high GWP to low GWP refrigerants	HFC refrigerant systems	Retrofit	-2-3/-5% (poorer) (also ETS cost savings)	Long
Use natural rather than synthetic refrigerants	All refrigeration systems	New Assets	1-3/5%	Long

A checklist of opportunities in more detail by area is available for download from EECA's Packhouses and Coolstores sector pathway.

3 The business benefits of efficient refrigeration

Refrigeration systems consume large amounts of electricity which contributes greatly to the running costs of businesses with considerable cooling requirements. In industry, refrigeration can be responsible for up to 86% of total electricity consumption, depending on the industry sector, as shown in Table 2. Improvements to technical elements of modern refrigeration systems have the potential to reduce energy consumption by 15% to 40%. Improving simple operational practices with minimal expense can often reduce energy costs by 15% or more. This will become more important as energy prices rise, the price placed on greenhouse gas emissions via the Emissions Trading Scheme (ETS) increases, and an increased focus is put on reducing fugitive emissions of high Global Warming Potential (GWP) refrigerants from industrial systems.

Table 2: Typical refrigeration-related electricity use in New Zealand[1]

Industrial sector	Electricity Used for refrigeration
Dairy Product Manufacturing	23%
Fishing (and Hunting)	80%
Meat & Seafood Processing	57%
Other Food & Beverage Manufacturing	30%
Retail Trade (Food)	64%
Wholesale Trade (Food)	86%

Note: portion of electricity used for refrigeration is the total electricity used in refrigeration compared to the total electricity used by the sector (based on 2022 data).

Energy efficiency businesses have:

- Reduced energy costs.
- Reduced operation and maintenance costs.
- Reduced resource consumption and greenhouse gas emissions.

Further, energy efficiency improvements often result in:

- Improved system reliability.
- Improved safety.
- Increased productivity.
- A better working environment.
- Improved quality of refrigerated products.

Money saved on power bills improves the bottom line directly, meaning it can be of greater value than increased sales.

4

What is your opportunity?

Delivering the best outcome for your business requires a whole-systems approach to the design, installation, operation and maintenance of your refrigeration system. Energy efficient operation of each individual component can achieve gains in overall system efficiency. However, the operation of each individual component can be limited by or impact the operation of other components. For this reason, the greatest system efficiencies can generally be achieved by taking a system approach, whether an existing system is being improved upon, a new system is being designed, or a service provider is involved.

Appendix A provides an overview of components used in industrial refrigeration systems.

Defining the limitations of your current refrigeration system is the key to finding the best solution to achieving energy efficiency for your business.

- Can I reduce my need for refrigeration?
- Can I make my system more efficient?
- Do I need a new refrigeration plant or system components?
- How do I expand my existing system?
- What do I need to know to install a new system?

This guide offers step-by-step solutions to help you identify opportunities to implement best practice to achieve energy efficiency in your refrigeration system.

Solution 1: Reduce your need for refrigeration

The first approach to achieving a more efficient operation is to review the need for refrigeration. This applies to both existing and new systems. A lower cooling duty (heat load or refrigeration demand) means lower energy use irrespective of the efficiency of the refrigeration system.

Review all the processes or products that need refrigeration. Is refrigeration needed at all or is there is another solution that can provide a cooling service without the need for refrigeration? Does each process need to be cooled to the degree it is currently being cooled to, and how can the heat load be reduced?

Solution 2: Improve the efficiency of your existing system

Do you have a refrigeration system that could be running more efficiently? If a complete retrofit upgrade cannot be achieved, incremental improvements can often be made by making small alterations and conducting simple maintenance practices.

Solution 3: Design a new system

Are you planning a brand-new refrigeration system? The costs of a new refrigeration system can sometimes quickly be recovered in energy savings over an old system. Life cycle costing of existing systems should be undertaken to determine when it is viable to replace it. If environmental impact is important, then also undertake a Life Cycle Assessment (Appendix B).

Are you expanding your premises and need to ensure that your refrigeration system will work effectively? If so, this will involve elements of both solutions. Firstly, minimise your required cooling duty (Solution 1). Secondly, ensure your existing system is running efficiently (Solution 2) and thirdly, if your system needs to be expanded, design the new components and modify the existing system to maximize the system's efficient performance (Solution 3). Following this process will ensure that you are not wasting money purchasing more refrigeration capacity than you actually need. Additionally, information gained from reviewing efficiency may guide the selection and design of the new components of the system.

4.1 Solution 1 – Reduce your need for refrigeration

The first step in any decision-making process is gathering information and getting a view on the scale and diversity of the issues under consideration. In the case of industrial refrigeration systems, this means identifying answers to the following questions:

Most importantly:

- Why is refrigeration needed?

Then:

- What is being refrigerated?
- Where is refrigeration needed?
- When is refrigeration needed?
- How much refrigeration is needed?

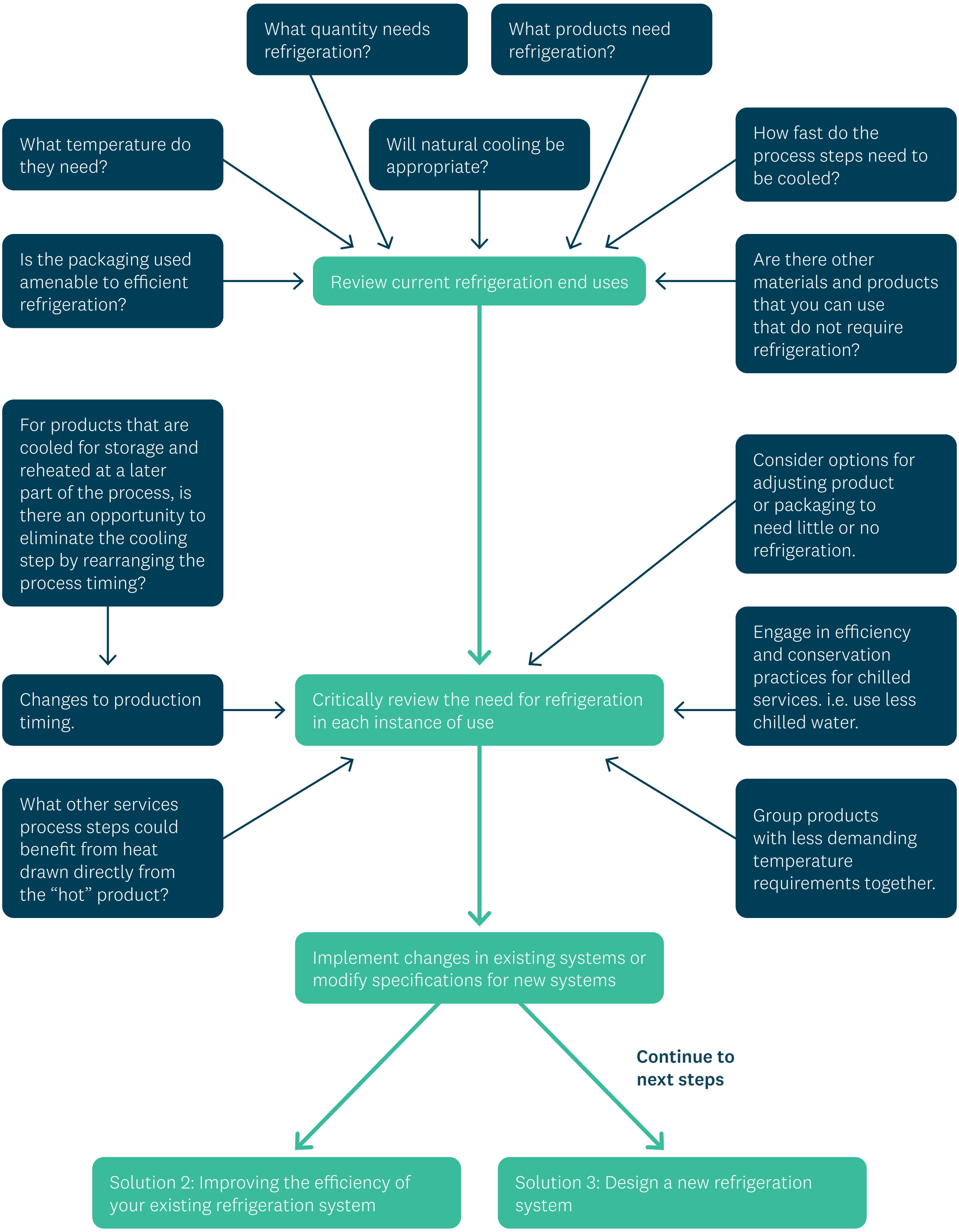
4.1.1 Step 1 – Assess the need for refrigeration

On a given site, refrigeration can be used for cold storage of goods and materials that go into a product, process cooling such as liquid chilling or product chilling or freezing, maintenance of working environments, and cold storage of finished frozen or fresh goods.

It is possible that with changes to the process, the product, or the raw materials, the need for refrigeration can be reduced or eliminated. It is important to review the need and temperature level of refrigeration required whenever such changes occur and to have a procedure which flags these changes as they occur. This ensures that these alterations do not result in current practices becoming inappropriate and unnecessarily wasting energy. For example, chilling or freezing products before they are packaged can hugely increase the efficiency of the chilling or freezing processes (the process is usually faster with less fan power and higher refrigerant temperatures without packaging). However, chilling or freezing unpackaged product may require investment in moulds to maintain product shape until packaging application prior to refrigerated storage.

A process to identify opportunities to reduce the need for refrigeration is shown in Figure 1.

Figure 1: Decision flow chart for determining the need for refrigeration



4.1.2 Step 2 & 3 – Review refrigeration demand

4.2.1.1. Assess the refrigeration heat load

Preparing a comprehensive list of products and cooling processes, and their specific cooling requirements, helps you to understand:

- What your theoretical refrigeration heat load should be
- Which processes dominate your refrigeration energy consumption.
- Which refrigeration load temperature needs can be grouped together, with potential benefits to your centralised refrigeration system operation.

A typical refrigeration heat load is made up of process cooling requirements (that is, cooling the product or space itself) and unwanted other heat gain, such as:

- Heat flows through walls, floors and ceiling of a cold room.
- Air infiltration through doorways into a cold room.
- Evaporator fan motors and refrigerant/coolant pumps.
- Processing equipment motors located within the refrigerated space.
- Lights and other electrical devices.
- People and product handling equipment such as forklifts and conveyors.
- Refrigerant/coolant pipework outside the refrigerated space particularly if it is uninsulated.
- Heat gains into the refrigerated space during defrost.

A process for creating a high-level estimate of the refrigeration heat load is:

1. Identify and quantify all major process-cooling loads by looking at equipment manuals and process/product specifications for each process. Such estimates may not very precise, but it will help target your more detailed investigation.

2. Investigate the major process cooling loads in more detail through measuring the flow rate of secondary coolant (if used), temperature change of the coolant, and its specific heat capacity. Where this is not possible due to lack of metering equipment, it is recommended that appropriate metering is installed as it will help with on-going improvements in the refrigeration system operation in the future.

3. Ideally, use data-loggers to measure flow rates and temperature changes. This can be time consuming and expensive and needs to be balanced against the savings possible.

Continue these steps until you have collected data on all the major cooling loads (greater than 80% of all loads). Your refrigeration supplier can assist you in doing this process as they often need to estimate cooling loads as part of specifying systems. An energy audit of the refrigeration system will help decide if major investment in the plant would be justified and help plan future capital investment.

4. As an alternative to steps 2 and 3, estimate the product related heat loads based on flowrates, specific heat capacity and inlet and final temperatures of the product instead of the coolant.

5. It is often difficult to estimate how much heat is being gained from the environment and other sources in addition to process cooling loads. One method is to estimate the energy ‘balance’ by considering each of the energy flows into and out of the system:

    a) Estimate all product cooling loads at the heat exchanger, cold room or process chiller/freezer based on product flowrates and inlet and final temperatures (items 2 to 4 above).

    b) Estimate the heat load passing through the thermal envelope from outside based on ambient temperatures throughout the year, the temperature of the refrigerated space, and the construction of the refrigerated space walls.

    c) Estimate heat load due to air infiltration based on the fraction of time that doorways are open, the typical measured air velocity through the doorways (using an anemometer) and the air temperature and relative humidity (RH) inside and outside the doorways.

    d) Estimate the heat load dues to all electrical devices operating inside the refrigerated space by measuring the electrical power use or summing the nominal power use by each of the fans, pumps, lights and other motors being used.

    e) Estimate the amount of refrigeration being created by the refrigeration plant compressors based on manufacturers’ data given the typical measured operating conditions and compressor power use.

    f) The difference between the refrigeration created by the compressors and the sum of the first four heat loads would be ‘other heat gains and efficiency losses’ that might be attributable to such effects as defrost, and heat gain through poorly insulated pipes passing through non-refrigerated spaces.

Such exercises are not trivial, and it is recommended that refrigeration plant operators seek the help of engineering staff or professionals experienced in this work.

4.1.2.2. Reduce the product process cooling duty

Some common product and process cooling load issues are summarised in Table 3. By addressing these, you will also be improving the efficiency of your refrigeration system.

Table 3: Some common product and process cooling load issues

Symptom	Problem	Measure
Temperature of the product reaching the refrigeration plant is higher than expected. If product is pre-cooled before reaching the refrigeration system, there is an ‘upstream’ problem.	Fouled process heat exchanger	Check upstream process and temperature control settings. Avoid product reheat between process areas. Precool product using ambient cooling.

Symptom	**Problem**	**Measure**
Product being cooled below required temperature.	Product temperature too low	Check temperature control system If possible, raise the coolant temperature and/or reduce coolant or air flowrate. Reduce product residence time
Heat load in a cold room higher than expected; frost & ice buildup faster than expected	Excessive heat and moisture ingress through cold room doors	Improve door closing 'discipline' Install rapid acting doors Check door seals, airlocks, strip curtains or other protection devices
Evaporator fans or pumps run when product or space has reached target temperature	Excessive fan & pump power	Ensure control systems maximise possibilities to switch fans & pumps off or reduce their speed
Cold room temperature too low	Incorrect control	Adjust the thermostat
Cold room temperature too high	Excessive cooling loads Inadequate cooling	Check that heat load is not too high (e.g. doors left open, excessively warm product load) Ensure evaporators are defrosted and operating with low superheat. Check refrigeration plant performance (for example, control system problems, fouled heat exchangers)

4.1.2.3. Reduce other heat loads

Potential solutions for reducing refrigeration heat loads are given below. As each product and process is different, consideration needs to be given to specific process temperature or other requirements before implementing these solutions, particularly in the food industry.

The potential solutions are:

- Allow ambient cooling of product before refrigeration.
- Consider pre-cooling of product in specialised pre-coolers (particularly for horticultural product storage).
- Minimise re-heating that occurs as product is moved between processing and refrigerated spaces.
- Raise the temperature of the coolant (or cold room air), if possible, without compromising product quality.
- Ensure insulation of the refrigerated space is adequate and in good condition (Section 4.1.e).
- Inspect building envelope insulation and repair damaged or poorly repaired areas.
- Increase insulation on pipework and avoid running pipework through hot areas or areas exposed to the sun.
- Paint the outside surfaces of insulation light colours (avoid dark colours), keep surfaces clean and shiny and/or use shading to minimise solar radiation gain.
- Ensure process equipment is operating correctly.

- If a washdown process is used within the refrigerated space, ensure the amount of hot water used is minimised, or use another cleaning method that does not heat up the space or add excessive moisture.
- Even when the refrigerated space is not in use, keep the doors closed to minimise heat gain into the space.
- Minimise air infiltration into a refrigerated space (i.e. open door for the minimum time to allow product movements and install door protection systems such as strip curtains, air curtain or air locks).
- Install seals, bump cushions or similar around load-out bays so that warm air entry into the refrigerated space is minimised during load-out or load-in of product and equipment. Make sure transport operators are using them correctly.
- Reduce time personnel spend in (or passing through) refrigerated spaces – change layout to improve product logistics, if possible.
- Ensure all cold services are separated from heating services as much as possible.
- Install more efficient evaporator fan motors and install controls to reduce speed (preferred) or turn them off when required cooling duty is significantly lower than design (Section 4.2.1.4).
- Install more efficient coolant pumps and turn off when not required (Section 4.2.1.12).
- Optimise defrost schedules – frequency and duration – to match the rate that moisture enters the refrigerated space from product and through doors (Section 4.2.1.2).
- Reduce lighting load in refrigerated spaces (use high efficiency lights such as LEDs and control them so they only operate when people are present).
- Check that underfloor heating systems for refrigerated spaces operating below 0°C are not “overheating”. Ideally, underfloor ground temperatures should be monitored, and the heating system controlled to ensure temperatures are not significantly greater than about 5°C.

4.1.2.4. Insulation

Insulation of refrigerated building envelopes and refrigerant and coolant pipework is important to minimise heat gain from the ambient. Some negative effects of uninsulated or poorly insulated coolant or refrigerant pipes include:

- The temperature of the refrigerant arriving at the compressor suction is higher than necessary (increased energy consumption and reduced refrigeration capacity by the compressor).
- Process conditions not being reached due to the refrigerant or coolant reaching evaporators at a higher temperature resulting in less effective heat transfer.
- Higher coolant flow rate (higher pumping energy) to compensate for the heat gain in secondary coolant loops.

In refrigerated buildings, the insulation of the building envelope should be regularly inspected. It is particularly important that during construction (or repair work) that conduction paths (or thermal bridges) are not created through the insulation. For example, metal bolts that penetrate the insulation panels greatly reduce the effectiveness of the insulation.

Insulation (both pipe and building envelope) should also be regularly inspected for water vapour ingress, as this can condense to water or form ice which both greatly reduces the insulation effectiveness. Vapour barriers should be used on the outside of insulated surfaces to prevent water vapour ingress. These should be installed if absent or incomplete and regularly checked for integrity.

Even with the best efforts to keep insulation dry and sealed, some moisture will still make its way into the insulation and cause a drop in the insulation performance over time when compared to its original newly installed performance. All insulating panel and closed cell insulation products deteriorate over time through the action of moisture, or the gradual replacement of the inert gases used as the foaming agent during manufacturing, with air. Any calculations of the heat gain through the building envelope must make allowance for this degradation.

Making use of thermal imaging technology can help identify “hot spots”. If using thermal imaging equipment, it is important to look at more than just the insulation. Examples of things you might find are:

- Hot spots in pipe insulation where the insulation has broken down or been removed for maintenance but not put back correctly.
- Hot spots on cold room walls due to thermal bridging.
- Warm patches on cold room walls where hot services are present on the other side of the wall.
- Hot spots around doors where the seals have broken down or are inadequate.
- Excessive heat from inefficient lighting.
- Obstructed air flow paths through evaporator or condenser fins.
- Differences in electric motor temperatures that may indicate less efficient motors or poorly performing motors (e.g. windings insulation deterioration).

4.2 Solution 2 – Improve the efficiency of your existing system

Typically, the reasons for inefficient refrigeration system performance are poor design, poor control, and poor maintenance. The latter two are relatively easy to fix, while the first reason is likely to require capital investment to address. In some cases, poor performance can be attributed to the current system requirements differing from the original design conditions.

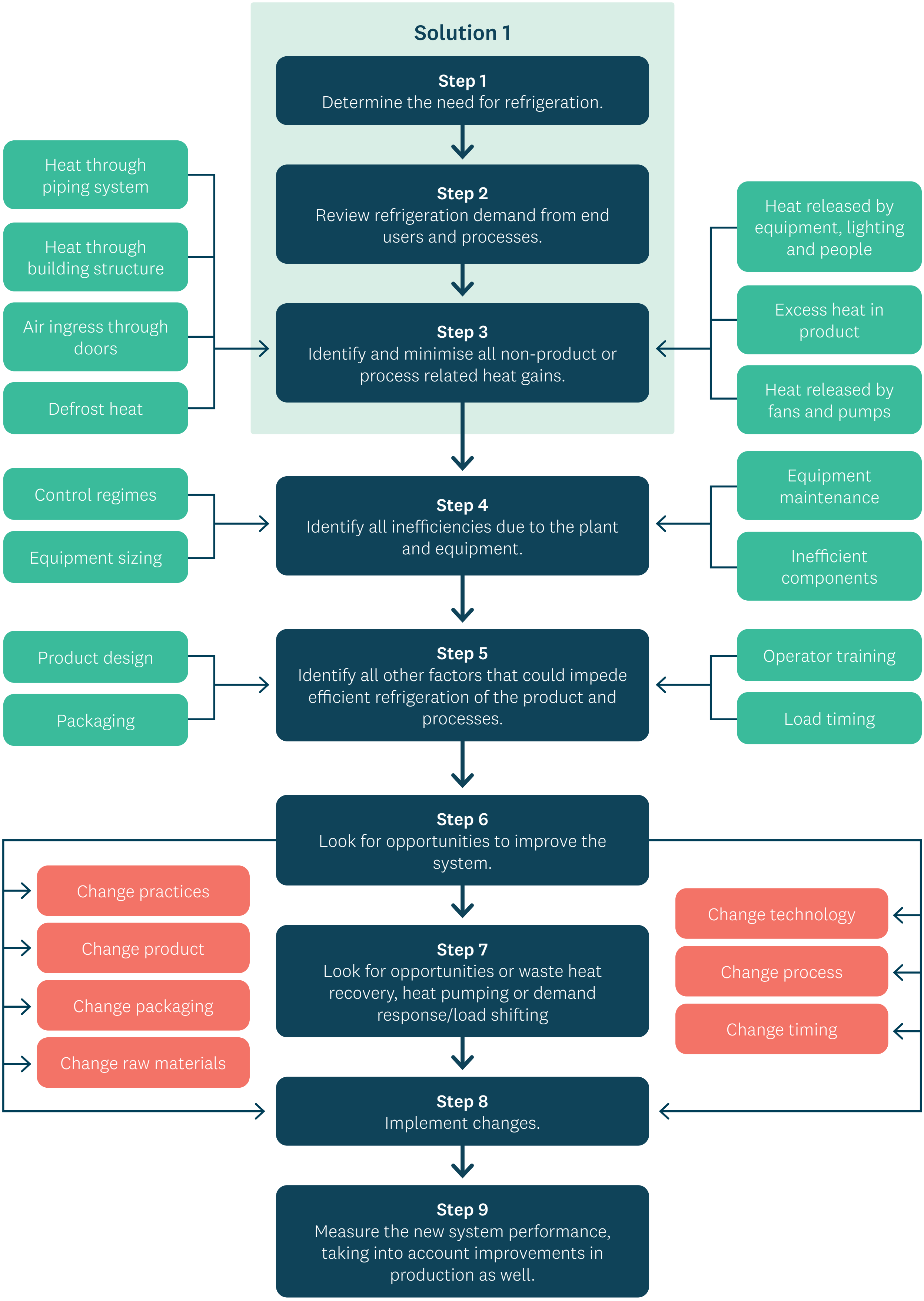
Challenges to improving system efficiency are:

- Large-scale improvements can require replacement of a fully integrated system and require significant capital expenditure.
- Some industries require 24-hour refrigeration, so that any alterations to improve the efficiency of the system requiring disruptive shutdowns are extensively avoided.
- Commonly held misperceptions of the energy performance gains that can be achieved by simple maintenance activities.

To determine the optimum time to replace a refrigeration system, a life cycle cost assessment (refer to Appendix B) should be undertaken for any plant over 10 years old. Some efficiency benefits may be realised from the use of new technology and an adequately sized new installation that reflects the current and projected production rates, and also fully integrates any ad-hoc modifications to the original plant that may have occurred over time.

However, even if a complete upgrade cannot be achieved, incremental improvements can often be made through a greater understanding of refrigeration systems, conducting simple maintenance practices and making small alterations. Figure 2 gives a suggested process to follow when looking for opportunities for efficiency improvements for an existing refrigeration system. The first three steps relate to minimising refrigeration heat load and are outlined under Solution 1.

Figure 2: Steps identifying energy efficiency improvements in an existing refrigeration system



4.2.1. Steps 4 to 6: Plant & equipment inefficiencies

4.2.1.1. Review refrigeration plant, controls, set points and heat rejection

Refrigeration system performance can be considered from a temperature point of view. *Temperature lift* is the difference between the evaporating and condensing temperatures. Minimising temperature lift is a key way to improve performance. A 1°C reduction in temperature lift can improve plant energy efficiency, known as the Coefficient Of Performance (COP) by about 2-3%. Temperature lift reduces if the condensing temperature is lowered and/or the evaporating temperature is raised. Raising evaporating temperatures also has a large positive impact on cooling capacity of compressors meaning that compressor run hours can be reduced.

The temperature lift and system pressures are directly related and so actions that can reduce the difference between the compressor suction and discharge pressure will also achieve system performance gains.

4.2.1.2 Improve evaporator defrosting

Moisture entering the refrigerated space will eventually end up condensing or freezing on the evaporator coils. For refrigeration systems where the evaporator surfaces are below 0°C, the formation of frost will begin to impede the flow of air through the evaporators as well as reduce the conductive heat transfer between the refrigerant and the air. Both of these effects work together to reduce the effectiveness of the evaporator. To maintain the efficient operation of the evaporator a defrost cycle is often used.

The defrost cycle includes:

- Stopping supply of refrigerant to the evaporator.
- “Pumping-down” the evaporator to remove all liquid refrigerant before isolating the evaporator from the compressor suction (optional).
- Stopping the fans.
- Starting the defrost heating mechanism.
- Terminating evaporator heating when all frost has melted.
- Restarting supply of refrigeration to the evaporator.
- Restarting the fans once the evaporator is back down to normal operating temperature.

Appendix A summarises the main defrost methods.

Ideally, all of the heat supplied during defrost melts frost and leaves in the melt water that is drained outside the refrigerated space. In reality, much of the heat suppled to the evaporator during defrost heats the metal in the evaporator and/or is loss via natural convection into the refrigerated space. The re-cooling of the metal and convection of heat and moisture into the refrigerated space represents extra heat load on the refrigeration system.

Timer Control of Defrost

A low cost defrost option is to use timers to initiate the start of the defrost cycle and to control the duration of the cycle. Such control can be inefficient because it does not respond to changing levels of moisture in the refrigerated space, and the duration of defrost will likely be set long enough to ensure complete defrosting occurs when the frosting is at its worst (too long at other times). Operating a defrost cycle too often and/or for longer than necessary increases the defrost heat load which results in more energy use by the refrigeration system.

A better option is to regularly reset the defrost timer controls to reflect rate of frosting due to moisture losses from the product (if any), the air exchange rate through doorways, and changing ambient conditions.

On-Demand Defrost

Although more expensive, the optimum solution is to install an automatic defrost control system that can detect the extent of frosting to initiate defrost and can detect when the coils have been fully cleared of ice to terminate defrost (“on-demand” defrost).

One method of triggering the defrost cycle is using airflow sensors and thermocouples to detect the amount of frost. An alternative is measuring the air pressure drop across the evaporator coil, which can be effective but can be difficult to make work reliably.

To terminate the defrost cycle, the most low-cost and reliable method is using a temperature sensor detecting a sudden rise in evaporator coil temperature when the slowest defrosting position on the evaporator becomes clear of ice. An alternative that can be used if refrigerant is left in the evaporator during defrost (i.e. the evaporator is not “pumped down”), is using the pressure of that refrigerant to terminate defrost.

Other Defrost Considerations

For large cold rooms with multiple evaporators, ensure that the evaporators are staged so that they do not all enter defrost mode at the same time to prevent large spikes in room temperature during defrost. The extra heat load due to defrost means that refrigeration system energy use usually increases during defrost periods.

Automated defrost systems should also be set to avoid defrosting during periods with high electricity prices, especially if electric defrost is used. At the end of defrost, to stop air from the “hot” evaporator being blown into the refrigerated space, refrigeration of the evaporators should be resumed without the fans running, and the fans only turned on once the evaporators have cooled to close to the operating temperature.

A useful way to assess whether defrost is optimally controlled is to measure the flow of frost melt water during a defrost cycle. Defrost termination should occur shortly after melt water stops draining – if defrost continues long after melt water has fully drained then this represents wasted energy due to the extra heat load it creates. If defrost initiation is working well, the amount of melt water should be similar for each defrost and equivalent to a level of frosting of the evaporators where the frost is starting to have a significant impact on evaporator performance. It should be noted that the optimal amount frost at defrost initiation will be different for each evaporator and so should be estimated by observation and measurement of the evaporator performance as frost builds up.

4.2.1.3 Improve condensers and reduce head pressure

Improving condenser performance and optimising condenser controls to reduce condensing temperature is a common opportunity to increase energy efficiency. The different condenser types and their respective advantages and disadvantages are described in Appendix A. Irrespective of condenser type, regular maintenance to maintain condenser performance is essential (Section 4.2.2.3).

The lower the ambient/water temperature, the lower the head pressure can be, which reduces compressor energy use. It is usually worthwhile to use a relatively small amount of energy to run the condenser fans/pumps motors to lower the head pressure, because this saves a large amount of energy use for the relatively large motors that run the compressors.

Most condensers have head pressure (condensing temperature) controls with a minimum head pressure setpoint located by the fan or pump variable speed drive (VSD) or on/off controls. For many systems the set-point is constant year around, irrespective of the ambient or water temperature. If the ambient/water temperature is high, then the setpoint will not be reached even with all of the fans/pumps are operating, and the head pressure will “float” as the heat rejection load and ambient/water temperature vary. The fans/pumps will only start controlling when the set-point is reached.

For energy efficiency, the head pressure setpoint should generally be set to the lowest value at which the refrigeration system will operate robustly (without the performance of other components being compromised). For most plants, there is usually little danger of setting too low a head pressure as the system will merely try to achieve as low a head pressure as is physically possible given the ambient conditions and condenser characteristics. Setting the head pressure to a very low value means the actual head pressure will “float” depending on the ambient conditions.

Aspects that might constrain the set-point include performance of thermostatic expansion valves or oil separators, or the manufactures’ specified operating envelope for the compressor. Such problems can often be cheaply overcome (e.g. by using an electronic expansion valve or using a different thermostatic valve orifices) so such options should be discussed with your refrigeration contractor.

However, for some systems the lowest possible head pressure setpoint will occasionally result in excessive condenser fan/pump power being used relative to the saving in compressor power. In such cases, optimal condenser fans/pump control will change the head pressure setpoint depending on a combination of the condenser heat of rejection load and the ambient/water temperature, such that the total of the condenser fans/pumps and the compressor power is minimised. Such a control system is difficult to set-up and is system specific, so it should only be attempted by qualified technicians. In general, such control usually means that the optimal head pressure setpoint approximately follows changes in the ambient/water temperature (commonly at least 5°C higher).

The simple approach of changing the head pressure setpoint on a monthly or seasonal schedule depending on the ambient conditions (e.g. higher in summer; lower in winter) may closely approximate the fully optimised control strategy. This is a more efficient practice than fixing the head pressure setpoint at the design condition, which is the maximum required to provide refrigeration on the hottest days.

4.2.1.4 Variable speed drives (VSDs) for evaporator and condenser fans

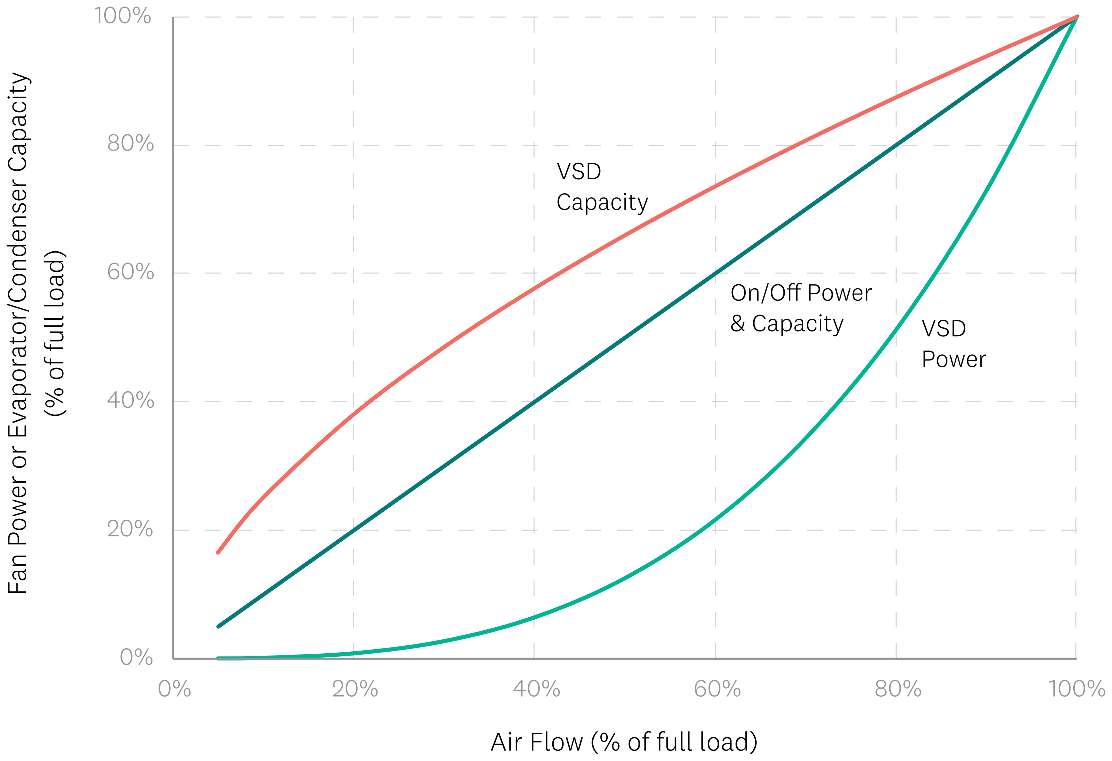
Use of VSDs for evaporator and condenser fans has the same advantages over on/off control as for pumps (Section 4.2.1.12). Figure 3 compares on/off control with VSD control of fans for an evaporator or condenser.

For on/off control air flowrate, evaporator/condenser performance and fan power changes in proportion to the fan fractional operating time. For VSD control of fans, air flowrate changes proportional to speed, but the energy use changes in proportion to speed cubed, and the effect on evaporator/condenser performance is slightly better than a proportional drop as air flow decreases. For example, if fan speed is reduced to 70% of full speed, the air flow will reduce to 70% (30% reduction), but fan power will reduce to about 34% (a 66% reduction) of full speed power (0.73 = 0.34) and evaporator/condenser performance will only reduce to about 80% of full speed performance (20% reduction). In contrast, for fans operated 70% of the time via on/off control, all of the air flowrate, fan power and evaporator/condenser performance would reduce to 70% of that if all the fans were operating all the time (less than half the savings of VSD speed control).

Further, if there are multiple fans on the evaporator/condenser and/or multiple evaporators/condensers, it is important that all the fans on all the evaporators/condensers are controlled in parallel by the VSD, rather than only speed controlling the last “trim” fan. If so, the VSD benefit on fan power is realised on all the fans rather than just a single fan. For example, if there are three fans on an evaporator/condenser then operating all three fans at 85% of full speed gives the same evaporator/condenser performance as two fans at 100% and one at 50% yet requires 14% less fan energy use in total across the three fans.

Two-speed fans are another good option for evaporator/condenser fans, although slightly less efficient than VSDs as the full range of speeds are not available (only off, low speed and high speed). As for VSD fans, if there are multiple two speed fans then, all fans should be controlled to a similar speed. For example, for 2 two-speed fans then the option of one fan being off and the other being on high speed should never be used if the duty is intermediate. Instead, both fans operating on low speed gives more uniform conditions and has lower energy use.

Figure 3: Comparison on on/off and VSD control of evaporator/condenser fans.



Condensers

If the head pressure controls regularly operate the condensers at part-load, then VSDs should be installed rather than relying on on/off control. The condenser fan speed control should be linked to the compressor head pressure management system and measurements of the ambient conditions as described in Section 4.2.1.3.

Evaporators

VSD fans on air-cooling evaporators can also have a good return depending on operating conditions. For condensers, the savings opportunity depends on the fraction of time that lower air flow rates could be used, and is generally only significant when only when cooling duty is significantly lower than the design duty. For example, in a cold room, a high air flow rate is required when warm product is being cooled to the storage temperature. However, once all the product is at the storage temperature only a low air flow rate is required to remove the heat that enters through the building envelope. In this case, significant energy savings would be possible by using a VSD to reduce the evaporator air flow rate. In contrast, a VSD would have little value in a product air-blast chiller or freezer that must always operate with a high air flowrate to fully chill or freeze the product.

A constraint on speed control of evaporator fans is that air distribution around the refrigerated space must be maintained at a minimum level to ensure a uniform temperature. Sometimes, if speed is reduced too much, parts of the space remote from the evaporators may be starved of air flow. Ducted air distribution can reduce this potential impact as the air distribution relies less on the air momentum exiting the evaporator to reach remote parts of the space. If evaporator fans speed control is being considered, then a minimum speed should be set, below which it is known that the air distribution is unacceptably affected. The minimum speed will vary from room to room, so trials to understand the room characteristics might be necessary to set the minimum allowable speed.

Installing VSD fan control when possible gives two lots of energy savings, as the energy to run the evaporator fans ultimately ends up as heat in the refrigerated space that must then be removed via the refrigeration system. Therefore, not only can VSDs reduce the energy to run the fans, but the refrigeration load is reduced too.

Automatic control of evaporator fans is preferable over manual control. The principle is that fan speed can generally only be reduced when the cooling duty is significantly less than the design duty (e.g. at night or weekends when production rate is lower, doors are shut, and ambient temperatures are lower). Understanding the cooling duty profile over days, weeks and seasons may allow fan speeds to be set by timers (e.g. a set lower speed at night or at the weekends or during winter). One possibility for fully automatic control is to use fan speed as the control variable for temperature control of the refrigerated space. If so, a minimum allowable fan speed should be set and if further temperature control is required once the minimum speed is achieved, then another form of control in implemented as a second stage (e.g. refrigerant liquid supply solenoid on/off control).

4.2.1.5 Improve part-load compressor performance

Compressor efficiency reduces considerably when run at part-load (Figure 4). Screw compressors with slide valve unloading have particularly poor part-load performance, cylinder unloading for reciprocating compressors has a moderate penalty, whilst the penalty for compressor with speed control via a VSD is generally small (although the penalty usually increases at speeds below about 40% of full speed and there is a small penalty at full speed due to the VSD inefficiency). Use of hot gas bypass for compressor capacity control is the most inefficient method but should rarely be encountered.

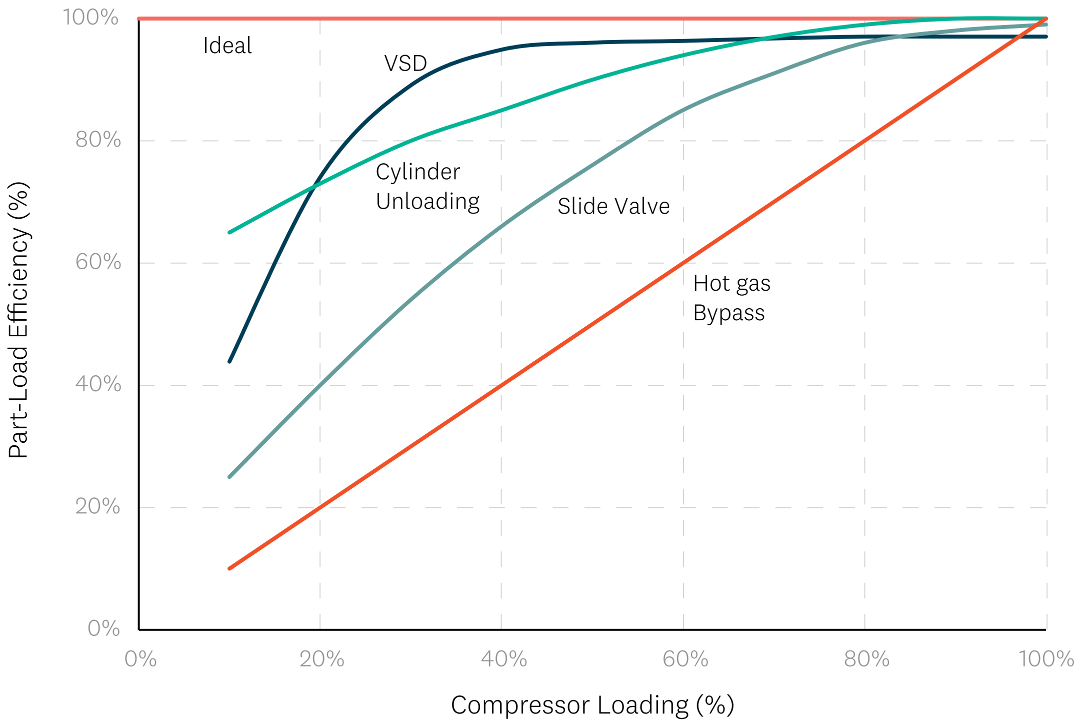
If there is only one large compressor on each suction, the best alternative is to implement and use VSD speed control if the compressor is VSD compatible (some motors are not suitable for VSD control). Your compressor manufacturer should be consulted before any retrofits, to determine what may or may not be possible. Most modern compressors have VSD control as a standard option.

Trim and Baseload Compressors

For a large refrigeration loads, it is generally more efficient to split up the load between a number of smaller compressors on a common suction and run the bank of compressors in a way that minimises part-load operation for any individual compressor (e.g. only part-load a “trim” compressor). A good strategy is to have one compressor with a VSD and to then ensure that the other compressors either operate fully loaded or off (baseload compressors), with the VSD compressor being the only one running partially loaded (the trim or load-following compressor). This captures the good part-load characteristics of the VSD without the capital expense of installing a VSD on all the compressors. Further, if the compressors on a common suction are of different sizes, then preferably the trim compressor should be the smallest compressor, so the part-load energy penalty is only incurred on the smallest fraction of the total cooling duty. However, the VSD trim compressor may have very long run-hours, which could become a maintenance issue.

If cooling duty is highly variable over short time periods, then selecting a larger compressor to be VSD controlled may help minimise too frequent stops/starts of the other compressors (motor overheating may be an issue), and/or avoid operating the trim compressor at very low speeds too frequently (part-load penalty higher).

Figure 4: Compressor part-load energy efficiency for different unloading mechanisms.



4.2.1.6 Controls to operate compressors at highest efficiency

Refrigeration systems can be operated automatically, semi automatically, manually or by a combination of the above system. Of these, automatically computer monitored and controlled systems have the potential to operate the system at the greatest efficiency. Some possible control issues are listed in Table 4.

Using automatic computer controls enables automatic sequencing of compressors so that they can run at optimum efficiency and be switched off when not required. This not only increases compressor and motor drive efficiency, but also increases operating life. A common constraint is that compressors cannot be turned off and on too frequently or their motors will overheat.

Ideally compressor controls on each common suction should allow the suction pressure to be as high as possible such that each refrigerated application connected to the suction can just be maintained at the desired temperature. However, most suctions operate with a fixed suction pressure setpoint and this setpoint is constant throughout the year.

For many systems, allowing the suction pressure to “float” so that temperatures in the “worst case” refrigerated application are just maintained is not practical because the control strategy can be difficult to implement and can lead to problems such as maldistribution of refrigerant distribution throughout the system. A simpler strategy of changing the suction periodically to follow cooling duty trends may achieve most of the benefits of a fully “floating suction”. For example, the suction setpoint might be raised when the cooling duty is known to be consistently lower for a reasonably long period of time (e.g. over winter, at weekends or at night) and then lowered again when cooling duty is known to increase (e.g. in summer, on workdays, during production shifts).

Regular review of suction pressure setpoints is advised even if a long-term fixed valve is required to ensure robust refrigeration system operation. Raising suction pressure setpoints can be assisted if cooling duties are minimised (Section 4.1.2.3), larger evaporator are installed (Section 4.3.8), evaporator performance is maximised (Section 4.2.2.2), pressure drops are minimised (Section 4.2.1.9), and/or if coolant storage can be used to smooth out cooling loads (Section 4.2.3.4).

Table 4: Possible control system issues

Symptom	Problem	Measure
Product temperature low; plant running even though target temperature achieved	Incorrect temperature controller setting	Check setting of main temperature controller. Check calibration and location of temperature sensor
In cool weather, discharge pressure is higher than expected	Incorrect head pressure control setting Poor condenser performance	Check head pressure control settings and ensure they are set at lowest practical level Check condensers for fouling, air/water flow and purge air
Product temperatures held but temperature control solenoid valves mostly off	Incorrect suction pressure control setting	Check suction pressure control settings and ensure they are set at highest practical level
More than one compressor runs unloaded most of the time on each suction	Poor control strategy	Change strategy so only a trim compressor is unloaded on each suction

4.2.1.7 Convert from liquid injection oil cooling to external cooling

Screw compressors usually require oil cooling and it is still quite common for them to use liquid injection oil cooling. Although liquid injection oil cooling systems are cheaper and simpler than external oil cooling systems, they act like an internal hot gas bypass which significantly reduces screw compressor cooling capacity and efficiency. Converting screw compressors from liquid-injection oil cooling to external (thermosyphon or fluid-cooled) oil coolers can give both cooling capacity and energy efficiency increases of between 3% and 10% leading to lower energy use and fewer compressor run hours. External oil coolers also may provide a heat recovery opportunity (Section 4.2.3.1).

4.2.1.8 Primary refrigeration system piping

For primary refrigeration systems, careful attention must be paid to pressure drops in the refrigerant piping. In particular, any pressure drop in either the compressor suction or discharge pipelines will require extra work from the compressor to overcome. The pressure drops in the system will be minimised by minimising the length of the pipe runs, the number and type of pipe bends (e.g. right-angle bends should be avoided), the number of valves (fully open valves still have some pressure drop), eliminating unnecessary restrictions and sudden expansions in the pipe system, as well as ensuring the pipe diameters are appropriate.

High pressure drops in the refrigerant liquid lines can affect the performance of control valves. In particular, expansion valve performance is significantly impacted if pressure drop in the liquid line causes partial flashing of the refrigerant upstream of the valve.

Insulation of pipelines and vessels in the low-pressure section of the primary refrigeration system is important due to the very high heat transfer possible when refrigerant boiling can occur. Any heat gain to the refrigerant in piping reduces the amount of useful cooling the refrigerant can do and so is a parasitic loss in energy efficiency for the system Section 4.1.2.4.

It is worthwhile noting that the pressure losses due to changing refrigeration load are not linear but instead are approximately proportional to the heat load squared. This means that any change in heat load e.g. increased production throughput) will have a disproportionate effect on the pressure drop of the system and hence large changes in the system performance. For example, a 25% increase in the production rate might increase the refrigeration load by 20% meaning that the pressure drop will increase by factor of approximately 44% (1.22 =1.44) with corresponding increase in energy consumption by the compressor. Further, this example illustrates the drop in system efficiency and performance that can arise when extra cooling processes or cold rooms are added onto an existing refrigeration plant due to compressor suction lines not being appropriately sized for the increased cooling duty. Hence the need to plan plant expansions carefully.

4.2.1.9 Compressor suction and discharge piping

The compressor discharge piping can often have a number of fittings close to the compressor for maintenance purposes, and removal of oil from the refrigerant. Therefore, it is important to ensure that all valves and fittings installed have the lowest flow resistance possible, and that the pipe diameters are adequate for the anticipated increases in cooling duty (e.g. due to future plant expansion).

Oil separators can have very high pressure drops, and so when these are present, they should be carefully selected and their pressure drop monitored to ensure their best operation and lowest pressure loss. Oil separator performance is most likely to a constraint when the compressor is operating with low head pressures. Therefore, oil separators should be sized for the lowest head pressure likely to occur over a year and not the summer design conditions, which normally have higher head pressure.

On compressor suction lines, high refrigerant vapour velocities are sometimes required to carry oil into the compressor, particularly in vertical riser sections. High velocities mean that the pressure losses through the fittings in that section of pipeline will also be high. Minimising riser sections and sloping suction lines down towards compressors can reduce the need for higher velocities. As with the discharge line, eliminating superfluous valves and fittings can achieve good efficiency gains.

For pumped circulation or flooded refrigerant systems, vertical risers in wet suction lines between the evaporators and separator vessels can cause problems with liquid logging. Flooded and pump circulation systems have a mixture of liquid and vapour leaving the evaporators, so there is a need to ensure the velocity of the vapour/liquid mixture is high enough to carry the liquid droplets out of the riser. If this does not happen, then the liquid can build up within the pipeline, causing a static head pressure drop, which ultimately lowers the required compressor suction pressure. To address this problem, the pipelines need to be designed to eliminate or minimise the height of risers, risers need to be adequately sized to keep the vapour velocities high, or the liquid can be separated from the vapour below the riser and separately pumped up the vertical lift. An alternative approach is to reduce the flow rate of liquid to the evaporators, but this will reduce the evaporator performance due to liquid starvation so is usually not the best approach.

4.2.1.10 Condenser piping

All piping from the condenser must allow for easy drainage of the condensed refrigerant from the condenser to the receiver. If the condensed refrigerant is not adequately drained via drop legs, then it will remain (“log”) in the condenser and effectively reduce the heat transfer area available for vapour to condense. If the available area is reduced, then the condensing temperature of the refrigerant must be higher to achieve the same amount of heat rejection which increases the head pressure that the compressor must work against.

4.2.1.11 Secondary refrigerant distribution system

Where a secondary coolant system is used, efficiencies may be gained by considering the distribution system and the components within it. The approach used is the same as would be used for any pumped system with a fluid at a temperature other than ambient.

The energy involved in pumping heat transfer fluids at higher rates than necessary around a system can be a significant waste of energy. This means you should check:

- If you are using the most appropriate secondary heat transfer fluid for your requirements (that is, pump the least amount of fluid practical; consider using fluids with a high heat capacity or a lower viscosity).
- That your pump system flexibly responds to variable refrigeration loads, rather than using the same amount of energy irrespective of the refrigeration requirement.
- That your insulation is in good condition.
- That pipes diameters are large enough to minimise pressure drops yet avoid unnecessarily high heat gain due to increased surface area.

By ensuring the secondary coolant circulation pump is not having to work against an unnecessarily high flow resistance (i.e. pipe diameters too small, or excessively long or convoluted pipe-runs), and having the minimum coolant flowrate, the pump energy consumption will be reduced.

The mechanical efficiency of the pump itself and the pump drives are also highly important, and energy-efficient motors, preferably with VSDs for control, should be used.

4.2.1.12 Variable-speed drives on pumps

When applied to pumps in the secondary coolant distribution system, more efficient flow control can be achieved by using VSDs or installing multiple pumps in parallel. VSDs are the preferred option when pumps operate for at least 2000 hours per year and process flow rate requirements vary by 30% or more over time.

In pumping systems with variable flowrate requirements, VSDs are an efficient alternative to throttling or bypass pumping control methods. VSDs save energy by varying the pump’s rotational speed. The flowrate through the pump varies in proportion to the speed. In addition, the lower flowrate through the piping network means that system pressure drop (and hence the pump pressure boost) reduces proportional to the flowrate (and pump speed) squared. The net effect is that pump power reduces in proportion to pump speed and flowrate cubed (as for fans). Hence at 80% of pump speed, the power is reduced to about 51% of full speed power (0.83 = 0.51). In contrast, reducing flow by throttled or bypassing has much lower effect on pump power (e.g. throttling increase pressure drops which counteracts the benefit of lower flow so the energy savings are much lower). It should be noted that VSDs only save energy in applications where the pump is operated at less than full load, as the saving derives from the improvements in system efficiency if both flow rate and pressure drop are decreased. In applications where the pumps are close to fully loaded most of the time, then the VSD may in fact slightly increase energy use, due to the small inefficiency of the VSD at full speed.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4.2.1.13 Control system optimisation

Control of compressors has been covered in Section 4.2.1.6, but the control system as a whole should also be considered to ensure that system operation and each component within it has been used optimally. This is a specialised area and it is recommended that the skilled staff such as the control system supplier's engineers are used.

A critical component in optimising a refrigeration system control system is ensuring there are enough measurements taken from throughout the plant that will allow the operators and the control system to know what is happening. The more measurements that are available, the more information the operators and control system will have available to make decisions. Observing the temperature and energy consumption trends over time will help identify problems with the control scheme and odd patterns that would otherwise not be obvious. Some examples are:

- Equipment such as evaporator or condenser fans not running at the right time.
- Poor load-in/load-out practices affecting temperature uniformity or rates of product cooling.
- Defrosting occurring too frequently or too infrequently (Section 4.2.1.2).
- Excessive moisture entering the refrigerated space through doorways causing significant deterioration in evaporator performance despite frequent defrost.
- Deterioration in condenser performance due to fouling and/or non-condensable gas build-up (Section 4.2.2.3).

4.2.1.14 Improve the product and room layout

The layout of the refrigerated space with respect to evaporator location, door placement, the presence of air flow ducting and guides and the packaging and arrangement of the product within the refrigerated space will have an impact on the efficiency of the refrigeration system.

For product air-blast chillers and freezers, good air circulation around and between each product item will help achieve a good heat transfer from the product to the air, which will allow higher air temperatures to achieve the same cooling rate compared with if the product were tightly packed or bulk-stacked. This will result in less work being required by the compressor.

Use of product racks to evenly space products in the air flow, blocking unwanted air flow pathways (e.g. using baffles) and using air turning vanes where air has to sharply change direction, all help to maximise air flow over product items and hence increase the rate of cooling while minimising fan power.

For product storage rooms where the product has been pre-cooled near to storage temperature, most of the air flow should be around walls and doors to prevent heat ingress from the ambient affecting product temperatures, and air flow through the product stack should be minimal. This requires ceiling and wall plenums (gaps) to allow adequate air flow around the outside of the space and for large spaces may require air ducting to ensure air gets to the space furthest from the evaporators. The benefit of improved air distribution will be less risk of product quality deterioration due to poor temperature control and the potential for reduced fan power.

4.2.2. Steps 4 to 6: Optimise maintenance

4.2.1.1 Overview

To avoid poor heat transfer and efficiency issues on an existing system, the refrigeration operator should have procedures in place for the regular monitoring and testing of overall performance, as well as servicing of all components as recommended by the manufacturers. This should be done routinely, as it can help identify problems early and has a large impact on energy consumption.

Monitoring gauges and switches on filters and valves can be installed to alert workers when system suction pressure drops too low or other malfunctions occur. A general maintenance checklist is available in Appendix C and more specific component symptoms and efficiency maintenance measures are available in the following Sections. Changes and repairs should be undertaken by qualified personnel.

4.2.2.2 Evaporator maintenance

Poor evaporator performance usually means that a lower evaporation temperature and compressor suction pressures will be needed to maintain desired air and product temperatures. Evaporator maintenance to maintain high performance should include:

- Checking the defrost system is working properly for air cooling evaporators (Section 4.2.1.2).
- Cleaning external evaporator surfaces to minimise fouling and air flow impediments (e.g. dust, packaging debris).
- Looking for damage to fins that could disrupt air flow and “combing out” any minor damage.
- Checking for uniform distribution of refrigerant and air across the evaporator (e.g. uniform frosting). If not, check fan operation, air flow impediments, refrigerant flow balancing valves and orifices in supply headers (flooded/pump circulation systems) or expansion valve distributors (direct expansion systems).
- Checking that all fans are operating.
- Ensuring that there are no extra pressure drops in the air circulation circuit that would reduce air flow through the evaporator.
- Removal of process-side fouling for process evaporators.
- Checking for contaminants in secondary coolants that could lead to fouling of evaporators and process heat exchangers.
- Checking expansion valve operation for direct expansion system (such that superheat is minimised and stable). If necessary, adjust super-heat settings, change the valve size (e.g. replace the orifice) or consider replacing thermostatic with electronic expansion values.
- Draining oil to minimise refrigerant side fouling (particularly for R717 systems).

4.2.2.3 Condenser maintenance

Poor condenser performance usually means that a higher condensation temperature and compressor discharge (head) pressure will be needed. Condenser maintenance to maintain high performance should include:

- Checking water treatment systems are working properly for evaporative condensers, water cooled condensers and cooling towers to minimise microbial growth and corrosion and fouling potential.
- Cleaning external condenser surfaces to minimise fouling and air or water flow impediments (e.g. dust, leaves, algae).
- For air-cooled condensers, looking for damage to fins that could disrupt air flow and "combing out" any minor damage.
- Checking that all fans and pumps are operating and, if applicable, that belt drives are not slipping.
- Purging non-condensable gases such as air. Presence of non-condensables can be checked by bringing the condenser to equilibrium with the ambient when the refrigeration system is not operating. If the refrigerant condensing temperature corresponding to the equilibrated high side pressure is higher than the ambient temperature, it indicates non-condensables are present. Non-condensables tend to accumulate in the high parts of the cycle where refrigerant velocities are low such as the condensers and liquid receivers. Note that automatic purgers can mask the extent of air leakage so if present check their frequency of purging.
- Ensuring that there is no short-circuiting of air from the condenser outlet back to inlet for air-cooled and evaporative condensers (temperature onto the condensers is significantly higher than the ambient).

Table 5 summarises maintenance measures that assist in maintaining condenser performance.

Table 5: Condenser maintenance

Air-cooled	Water-cooled, Evaporative and Cooling towers
Keep coils clean Ensure fans running correctly Shade condenser Ensure all control systems working	De-scale tubes Maintain water quality Ensure packing materials are clean and achieving an even distribution of air and water Maintain pumps and fans Ensure all control systems working

4.2.2.4 Compressor maintenance

Compressor faults can be difficult to identify but are generally caused by either a mechanical issue or internal blockages. Checking for oil levels, listening for worn bearings and checking for leaks should be undertaken periodically. For open drive compressors, regularly check drive shaft alignment or that belt drives are in good conditions and properly adjusted to minimise belt slipping, and that air flow for motor cooling is not impeded.

4.2.2.5 Refrigerant leaks

For all refrigeration systems detailed records of refrigerant removal and recharging during service should be kept. These support emissions reporting and enable identification of slow fugitive leakage of refrigerant that should be addressed. Control and elimination of refrigerant leaks has multiple benefits:

- Reduced emissions of potentially environmentally damaging gases.
- Avoided need to purchase replacement refrigerant.
- Cost savings through better refrigeration system performance.
- Avoided safety hazard especially if the refrigerant is flammable or toxic (all refrigerants are asphyxiants).

If a system operates with a refrigerant charge that is too low, then the evaporator will become starved of liquid refrigerant and will lose performance. This will cause the system to operate at a lower suction pressure (evaporating temperature) to attempt to maintain the application temperatures, leading to higher compressor run times and energy use. Symptoms of significant losses of refrigerant charge due to leaks include: bubbles in sight glasses; heavily frosted air-cooling evaporators; lower than design suction pressures; longer compressor run hours; and higher energy use.

Regular checks of the mechanical integrity of the refrigeration system equipment and piping (e.g. corrosion, mechanical damage) and for refrigerant leaks (e.g. seals) should be undertaken. A number of different leak detection systems are available depending on the refrigerant including:

- Ultrasonics that detect the sound waves from a leak
- Infra-red sensors
- Heated ceramic diode sensors
- Conductivity of metal oxides sensors (semi-conductor)
- Halide torch (flame colour change)
- Chemical sensors dedicated to specific chemicals or groups of chemical e.g. hydrocarbons
- Soapy water solution that show leaks as bubbles
- Fluorescent dye in oil is deposited outside the leak and shows under UV light

Complete elimination of leaks can be difficult. Slow fugitive leaks may remain below detection sensitivity. Also, small leaks can be intermittent, making them harder to find.

The option of replacing high GWP refrigerants in existing systems with lower GWP alternatives is discussed in Section 4.3.5.

4.2.2.6 Maintaining refrigerant quality

There are two main conditions attributable to the refrigerant that can contribute to poor system performance:

- Non-condensable gases in the refrigerant (covered in Section 4.2.2.3).
- Water absorbed into the refrigerant (particularly important for ammonia refrigeration systems operating with suctions in vacuum).

Ammonia readily absorbs water, that typically enters the system through air leaks or poor maintenance. While air can be purged, the water remains, altering the refrigerant's thermodynamic properties and requiring lower pressure for the same evaporating temperature. The water also leads to increased corrosion, fouling, and potential component failure, along with compressor oil breakdown and sludge formation in evaporators.

High water levels are most likely in leaky systems operated in a vacuum. Regular testing for water contamination should follow significant air purging. Water contamination below 2% has minimal impact, but above 5%, water removal is recommended to maintain performance. There are two main methods for removing water. For small systems, ammonia can be drained, and the system dried with nitrogen before recharging. For larger systems, an evaporator can be isolated as a rectifier, allowing distillation of ammonia and drainage of accumulated water. Rectification is time-consuming and costly, so operators should weigh the higher energy and maintenance costs against the installation of a rectifier or refrigerant replacement. For systems operating regularly in a vacuum, installing a rectifier is usually cost-effective.

For refrigerants other than ammonia, then water is usually immiscible. Therefore, the water will tend to drop out of the refrigerant in the low temperature parts of the system and cause problems such as icing up of valves. Most refrigerants other than ammonia are selected to operate above atmospheric pressure so the only time that air and moisture can enter the system should be during construction and maintenance. If good practices are followed the amount of air and moisture should be very small and the combination of air-purging during commissioning and maintenance and regular replacement of filter-dryers should prevent on-going negative effects due to water in the refrigerant.

4.2.2.7 Maintenance of insulation on pipework and vessels

To minimise the addition of unwanted heat loads, the insulation on all pipework, and fittings on the cold side of the refrigeration system must be kept in good condition (Section 4.1.2.4).

Regular inspections are recommended and should look for:

- Insulation disturbed by previous maintenance work on the pipelines or system components.
- Damage to insulation by vehicles and mishandled equipment.
- Formation of frost and ice around parts of the refrigeration distribution system.
- Places where insulation has been removed and not replaced.
- Evidence of water dripping onto the insulation (i.e. rust patches).
- Rips in the moisture barriers.

- Exposed flanges and valve fittings (expect to see condensation or ice on these).
- Evidence of insulation and cladding layers delaminating.

Where the insulation has degraded it should be replaced, and the moisture barriers and cladding replaced or reinstated.

4.2.2.8 Maintenance of cold rooms

Any degradation of the cold room will increase the refrigeration heat load. Regular inspection should look at the condition of the following aspects:

- Door seals – The door seals should be in good condition with no gaps between the door and the surrounding floor, walls, and ceiling.
- Door opening – Check that automatic door opening sensors are working and only keep doors open for the minimum time to allow forklifts to safety pass through the doorways.
- Door protection – Check that strip curtains are in good conditions – replace missing or torn strips; for air curtains check that the fans are working and the angle of the air curtain relative to the doorway is that recommended by the manufacturer.
- Insulation – Look for moisture or ice forming on the outside of the cold room. Patches are likely to indicate local breakdown of the insulation layer. Make sure there cladding, and moisture barriers are undamaged. Repair any panels that have been damaged.
- Thermal bridges – where bolts and structural steel penetrate the cold room walls, they should be capped on both sides of the panel with insulating caps. Where possible and practical, all steelwork passing from one side of the thermal envelope to the other should either have a thermal break inserted or have insulation placed around them to isolate them from the refrigerated space as much as possible.

4.2.1.4 Trouble-shooting

Maintaining your system and improving its efficiency often involves trouble-shooting. Tables 3 and 4 give some trouble-shooting guidance related to product/process cooling loads and control system issues respectively. Table 6 provides some further general trouble-shooting guidance.

Identifying the critical issue from a number of possibilities may require cross-referencing of multiple symptoms. For example, if both suction and discharge pressures are lower than expected, suction superheat (temperature) is higher than expected and application temperatures are too high, then low refrigerant charge is the most likely issue.

Table 6: General trouble-shooting guidance

Symptom	Potential Issues	Measure
High head pressure	Condenser performance impaired Non-condensable gases present Incorrect controller setting (spare condenser capacity) Refrigerant over-charged (high subcooling) Excessive pressure drops	Check condenser performance (Section 4.2.2.3) Purge non-condensable gases Check that head pressure control settings are at lowest practical level given ambient conditions Reduce refrigerant charge Check discharge line & oil separator sizing and that no liquid logging in condenser
Low head pressure	Incorrect controller setting Low refrigerant charge	Check head pressure control settings are at appropriate level given ambient conditions Top-up refrigerant charge after checking for leaks
Low suction pressure	Evaporator performance impaired Incorrect control setting Poor expansion valve performance Low refrigerant charge Excessive pressure drops	Check evaporator performance (Section 4.2.2.2) Check suction pressure control settings are at highest practical level Check that expansion valve is sized correctly, that superheat setting is as low as possible, and that no flashing in liquid line Top-up refrigerant charge after checking for leaks Check suction line & valve sizing and that no liquid logging in vertical risers

Symptom	Potential Issues	Measure
High suction pressure	High heat loads Compressor undersized or faulty/worn Incorrect control setting (spare compressor capacity)	Minimise heat loads (Section 4.1.2.3) Check compressor sizing relative to heat loads or compressor overhaul/ replacement Check suction pressure control settings are appropriate given application temperatures
High discharge temperature	High head pressure Low suction pressure High suction superheat (direct expansion) Poor oil or compressor cooling system performance (if present) Compressor worn/faulty High heat loads	See above See above Check expansion valve sizing & superheat setting Check coolant flowrates and control setpoints Compressor overhaul/ replacement Minimise heat loads (Section 4.1.2.3)
Low discharge temperature	Incorrect control setting Liquid carry-over	Check head pressure or oil/ compressor cooling control settings are not too low Check expansion valve superheat settings are not too low or that the liquid separator is not undersized.
High suction superheat	Expansion valve performance impaired Low refrigerant charge	Check expansion valve sizing & superheat setting Top-up refrigerant charge after checking for leaks

Symptom	Potential Issues	Measure
High energy use	High heat loads Evaporator or condenser performance impaired Incorrect control settings Worn or faulty compressors	Minimise heat loads (Section 4.1.2.3) Check evaporator/condenser performance (Sections 4.2.2.2 and 4.2.2.3) Check suction & head pressure control settings are not too low or high respectively; or that compressors not operating highly unloaded Compressor overhaul/ replacement
High application temperatures	High heat loads Evaporator performance impaired Incorrect control settings Compressors undersized or worn/faulty	Minimise heat loads (Section 4.1.2.3) Check evaporator performance (Section 4.2.2.2) Check suction pressure control settings are not too high Check compressor sizing relative to heat loads or compressor overhaul/ replacement

4.2.3 Step 7: Heat recovery and load shifting opportunities

4.2.3.1 Heat recovery at oil coolers

It is possible to recover waste heat from the screw compressor oil coolers for heating requirements such as potable hot water or boiler feed water pre-heating. The amount of heat available from oil coolers is typically less than 20% of the total condenser heat of rejection but often temperatures as high as 60°C can be achieved. If potable hot water is required, then an intermediary water loop may be necessary to minimise the risk of contamination by the refrigerant and oil if there is a leak in the oil cooling heat exchanger. Where there are suitable heating demands, and heat recovery does not lower system efficiency, heat recovery represents industry best practice.

An important consideration when utilising heat recovery is the relative timing of heating and cooling loads. If heating loads are not required at the same time as cooling loads, then a hot water storage tank or similar must be used to store the recovered heat until it is needed.

4.2.3.2 Heat recovery from the condenser

There are significant quantities of low-grade heat dumped to the ambient air or water from the refrigeration system condenser. This heat can be recovered for use in other services such as space heating during winter, preheating process water services, heating glycol for defrost or underfloor heating systems for freezers and frozen storage rooms.

If a desuperheater is used upstream of the condenser, then up to about 15% of the condenser heat of rejection can be recovered at higher temperatures (up to about 60°C) depending on the refrigerant's propensity to develop superheat during compression and whether there is also an oil cooler.

Heat recovery from the main condenser is constrained to achieving temperature less than the refrigerant condensing temperature. It is generally not cost-effective to artificially keep the head pressure setpoint higher in order to increase heat recovery temperature. Normally the best approach is to minimise the head pressure as outlined in Section 4.2.1.3.

When investigating condenser heat recovery, both the amounts and timing of the low-quality heat generated and the low-quality heat demand needs to be carefully considered so that the two match. Heat recovery from the condenser is often not cost-effective unless there is a large demand for low grade heat on-site.

4.2.3.3 Heat recovery via heat pumping from the condenser

Another option for heat recovery from the condensers is to use them as the heat source for a so-called high-stage heat pump or high temperature heat pump (HTHP). Currently, the most common HTHPs use ammonia as the refrigerant but other refrigerants can be used. Effectively the condenser for the refrigeration system becomes the evaporator for the HTHP. The condensing temperature for the HTHP is usually between 60°C and 90°C which allows heat recovery to temperatures approaching these values which is often much more valuable than at refrigeration condenser temperatures.

If the same refrigerant is used in the HTHP as in the refrigeration system, then the two system can be directly connected (the discharge header from the refrigeration compressors is used as the suction header for the HTHP). If different refrigerants are used, then a cascade heat exchanger is required to separate the two cycles. Even if the same refrigerant is used in the HTHP, a cascade heat exchanger is often employed so that the oil in the two systems can differ and best match the different temperature ranges in the two systems.

To maximise utilisation of the HTHP, it should be sized to either:

- Match the heating demand at the high temperature (with residual heat rejection from the refrigeration system via ambient condensers operating in parallel with the cascade heat exchanger).
- Or to match all of the heat rejection from the refrigeration system (with residual high temperature heating demand via boilers or a HTHP using the ambient as the heat source).

4.2.3.4. Instantaneous reserves and load shifting

Many refrigeration systems have large thermal mass, which means that the increase in temperature when they are turned off is slow. Examples of large thermal mass are storage vessels for secondary coolants and cold rooms with lots of stored product. This means that many refrigeration systems are suitable to act as interruptible load or for load shifting.

Your potential for savings due to acting as interruptible load or by load shifting will depend on your electricity supply contract and how tariffs change over time, and the degree of exposure to the spot market. You should work with an energy supply expert to investigate options.

Interruptible load

Interruptible loads can be contracted to provide instantaneous reserve capacity to Transpower to help with electricity frequency control (e.g. if a large generator or the HVDC link suddenly go off-line). There are two types of instantaneous reserve – Fast Instantaneous Reserve or Sustained Instantaneous Reserve. The requirements for biddable interruptible load include that the load can be automatically activated within fractions of seconds from dispatch due to an event and can stay off-line for at least 1 minute (but seldom for more than a few minutes). The dispatch of interruptible loads is relatively infrequent.

> Many refrigeration systems, particularly those providing refrigerated storage rather than process cooling, are able to act as interruptible load as the impact on product quality from going off-line for a short period would be minimal. Acting as interruptible load does not significantly change energy use but can generate additional revenue that lowers the effective price of electricity.

Load shifting

Loads shifting is where a refrigeration system (or parts of the refrigeration system) is turned off to reduce electricity use when electricity prices/tariffs are high. The plant then resumes operation in lower price periods. High electricity costs can be due to high unit charges or if a new peak demand use is likely to be set (if electricity tariffs include peak demand charges). Typically, high unit price periods are winter weekdays in the early morning and early evening when domestic electricity demand is highest. Load shifting to avoid high unit price periods would usually be for between 30 minutes and four hours duration at a time, once or twice a day. Load shifting for peak demand avoidance is usually for a fraction of each 15 or 30 minute billing period when peak demand charges apply (e.g. for 5-15 minutes each 30 minute period in the morning and evening peak periods) and a higher peak demand looks likely to be set.

Turning off refrigerated rooms holding product for load shifting for more than 30 minutes will result in temperature fluctuations that could adversely affect product quality so load shifting should be implemented carefully. During off-periods, the room fans should be operated on low speed or intermittently to minimise temperature stratification in the room. In general terms, frozen products are less sensitive to temperature fluctuations due to load shifting than chilled products. Also, for frozen product there is the possibility to pre-cool a room prior to an off period, so that it acts like a “fly-wheel” and can then be off for longer. Chilled products are both more sensitive to temperature fluctuations and often cannot be pre-cooled to colder temperatures due to the possibility of partial freezing. Therefore, load shifting for rooms with chilled product should only be considered if the impact on product quality is well understood and is deemed acceptable.

Use of a secondary refrigerant system provides the opportunity for thermal storage using a large storage/buffer tanks to hold the coolant. With coolant storage, even if cooling duty is highly variable, the coolant can be cooled by the primary refrigeration system at a more uniform average rate. Therefore, the refrigeration system can be smaller capacity and can be controlled to operate more efficiently, with the buffer in the storage providing capacity for peak cooling demands. Alternatively, the storage could be “charged” during low electricity cost period and “discharged” in high electricity cost period so that the net cost of providing refrigeration is reduced (load shifting). Such load shifting does not significantly change energy use but can lowers the average price of electricity consumed. If load shifting is practiced, then the system may not be able to be additionally used as an interruptible load.

The size of the storage needs to be matched to variation in cooling duty or the durations of load shifting that are anticipated. A large storage capacity might allow the capacity of the refrigeration system to be reduced so there can be a capital cost trade-off that requires detailed analysis to achieve the lower life cycle cost.

4.2.3.5. Solar Power

Many refrigerated buildings have significant roof area suitable for installation of solar photovoltaic panels. Such panels would both help shade the roofs from solar gain and generate power to partially off-set that used by the refrigeration system. The solar power generated is likely to be highest during summer days when the demand for refrigeration and use of energy is also highest. For more information consult the commercial solar guide on the EECA website.

4.2.4 Step 8 & 9: Measure the improvement

Throughout the improvement process, you can assess changes in performance quickly by comparing baseline performance to actual performance after individual system modifications have been completed. There are two ways of measuring plant performance and improvement. The first is to take an 'instantaneous' snapshot of the system. Measurements that should be taken and compared to design parameters are:

- Refrigerant temperature at the condenser inlet and outlet.
- Refrigerant pressure at the condenser.
- Air or product temperature at the evaporator inlet and outlet.
- Refrigerant pressure at the evaporator.
- Refrigerant pressure and temperature at the compressor suction and discharge.
- Power to the compressor.
- Power to the rest of the refrigeration plant (ideally separately for each of plant room pumps and fans, condenser pumps and fans, refrigerated room fans and lights, and forklift charging).
- Ambient temperature and relative humidity or cooling water temperature.
- Secondary coolant temperature at the inlet and outlet of the evaporator (if applicable).
- Product or refrigerated room air temperature.
- Product flowrates through process chillers and freezers (if applicable).

The condensing temperature and compressor discharge pressure (and consequently compressor power) should usually be considerably lower than the design condition which is for the maximum cooling duty on the warmest day. If the refrigeration plant always performs at the design condition, regardless of ambient temperature and production rate, then there is likely to be considerable opportunity for energy efficiency improvements. The performance of each evaporator and condenser should be compared with manufacturers' data to check there has not been any significant performance deterioration.

The second method is to do an energy consumption assessment. In this method, the systems baseline operating performance characteristics including energy usage are logged along with ambient temperature and production throughput for process chillers and freezers. Monitoring over time should allow the trends between energy use, ambient temperature and production throughput to be identified (e.g. via a plot of energy use versus ambient temperature or production throughput or using regression analysis or equivalent to curve-fit the data).

An improvement in the system performance after adopting a particular energy efficiency measure should be shown by a step change reduction in refrigeration system energy use when compared against the historical data for the same level of production and ambient temperature.

Metrics that might be useful to estimate and compare over time include:

- Specific energy use per m3 of refrigerated store (kWh/m3 per month or year) for refrigerated storage.
- Specific energy use per kg of production (kWh/kg over a defined period) for process chillers and/or freezers.
- System COP as in Appendix A (total cooling duty/total refrigeration system energy use) noting that the total cooling duty can be difficult to measure or estimate for many sites with multiple refrigerated applications.

There are national and international benchmarks for such metrics which can allow comparisons with similar facilities elsewhere or best practice targets.

One way to assess refrigeration plant performance is to ask the plant supplier or maintenance contractor to prepare a table of estimated COP for different operating conditions (ambient temperature and part-loading) and then compare this with the actual system COP over time. Tracking refrigeration cooling duty and refrigeration system energy use under a range of conditions before and after the improvements gives a good indication of the savings achieved.

4.3. Solution 3 – Design a new system

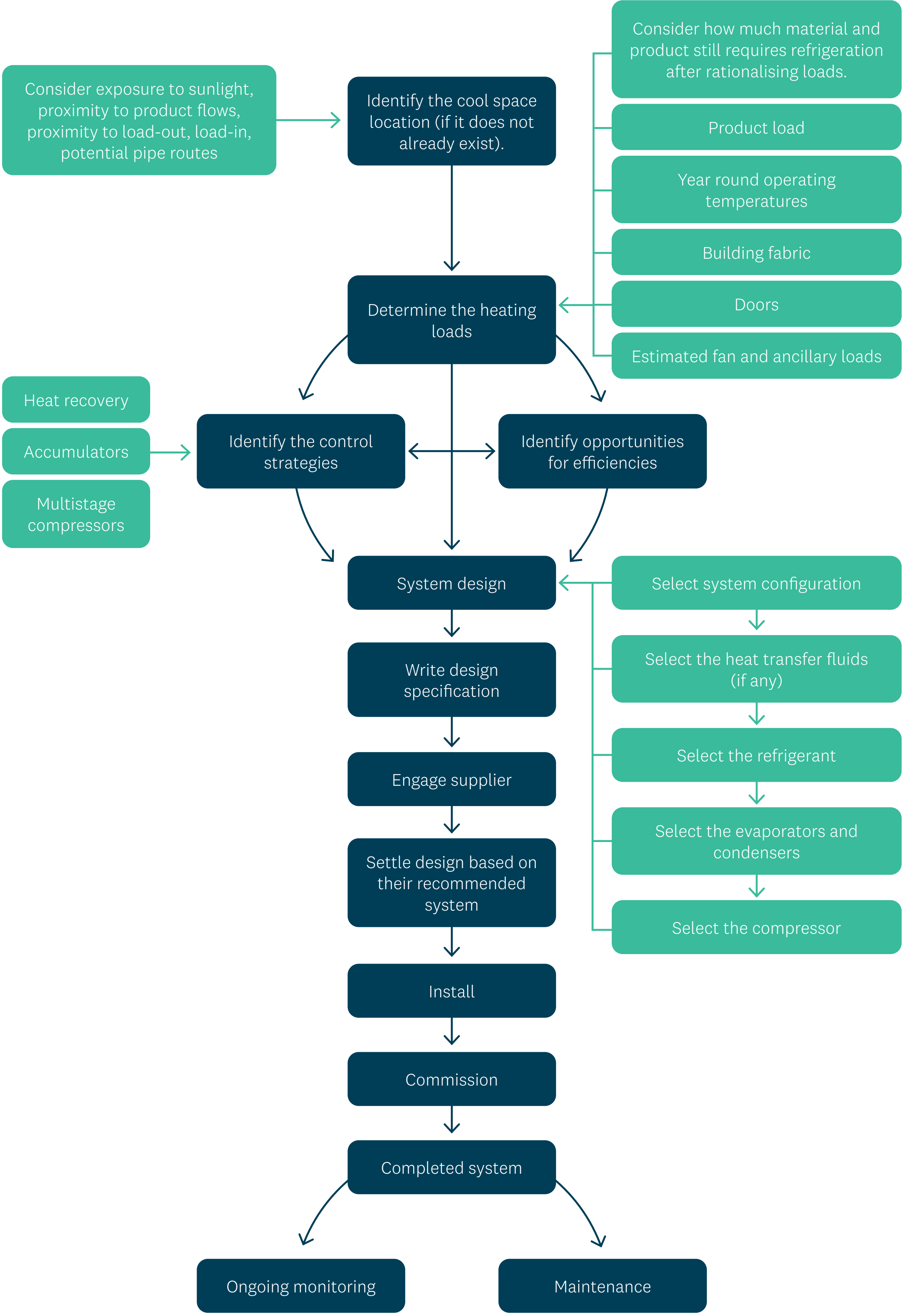
The costs of a new refrigeration system can sometimes quickly be recovered in energy savings over an old system. Life cycle costing of existing systems should be undertaken to determine when it is viable to replace it (Appendix B).

When designing a new system:

- Review current and estimated future cooling requirements.
- Detail refrigeration requirements over the year and provide this information to potential suppliers.
- Identify opportunities for heat recovery as early as possible.
- Ensure designs minimise heat gain (for example, through efficient equipment, good pipe and building envelope insulation, automatic and protected doors) as described in Section 4.1.2.4.

A suggested process to follow when designing a new refrigeration system is given in Figure 5.

Figure 5: Process for designing a new system



4.3.1. Design with a whole-system approach

Taking a whole-system approach is critical when designing a new system, as this presents the greatest opportunity to incorporate energy efficiency throughout the whole process, unhindered by the constraints that may be posed by existing equipment. Taking a whole-system approach entails considering the system operation as a whole rather than just focusing on individual components, as each component has flow-on effects that impact on other components, and therefore the efficiency of the system as a whole.

Many of the considerations for whole-system design and selection of individual components that were introduced in Solution 2 also apply when designing a new system. Because the whole system approach will include on-going performance monitoring of the effectiveness of the system, as the equipment ages maintenance will able to be targeted more effectively.

The target for the whole system approach is to design for the lowest life-cycle cost of the system. It is therefore likely that the designed system will not be the lowest purchase and installation cost due to the need for higher quality components, more care in design, installation of energy efficiency equipment such as heat recovery systems and VSD drives, and the need for more sophisticated control systems. A lowest first cost system will generally result in a system that is more expensive to operate.

To clearly reinforce the end target, all tender documents produced and purchasing decision guidelines should refer to the lowest life cycle cost.

Ensuring good design is critical to achieving the best performance and lowest life-cycle cost for the system. The costs associated with undertaking good design are significant and should be considered as a good investment in getting the best from the whole project. Like any good investment, good design has a payback period. If the design stage is poorly done, then the value of all following project steps will be diminished. For this reason, a competent designer needs to be engaged rather than using a general contractor who will be likely to be relying on the advice from the equipment suppliers.

Section 5 provides more information on selecting appropriately skilled project personnel. Businesses providing refrigeration system design services will often have access to software (both commercially available and propriety) to assist with the design including estimation of heat loads, refrigerant properties, refrigeration cycle analysis, component selection, and seismic or other mechanical strength design considerations.

4.3.2. Design for year-round efficiency

Quite often, refrigeration systems are designed for the peak cooling demand (which only occurs for a few days a year). That means the systems run for considerable periods at part-load, which can be highly inefficient if poorly designed. A new system should also be designed for high efficiency at part-load performance over the entire year and yet still meet peak demand. It is particularly important to ensure that design decisions do not impact on the capability of the operator to run the refrigeration plant with as low a compressor head pressure, and as high a compressor suction pressure as is possible. Using a systematic approach, any designs should also consider minimising the thermal loads on the system and reducing variations in the load over time. Where possible, the more constant the heat load is, the more closely the refrigeration system will be able to be matched to the load.

A good way to assess the range of operating conditions is to develop a table of the existing or predicted cooling loads versus ambient temperature (and production rate for a processing facility) and the amount of time this occurs per year. The designers and tenderers can then use this information to predict the energy consumption over the year. This analysis may be quite involved and so it is recommended that it is done by personnel with the appropriate skills.

4.3.3. Estimate heat loads

The most important initial consideration is the total cooling load. When quantifying the cooling load, the following should be estimated:

- Cooling required by the product, including maximum, minimum and average cooling demands that result from different product volumes and different throughputs of product. A clear understanding of the required product temperatures is needed.
- Heat gain through the building envelope after deciding insulation levels.
- Heat gain due to air exchange through doorway from knowledge of product loading patterns and after deciding door types and levels of protection.
- Heat sources within the refrigerated space (e.g. people, motors, lighting, etc).
- Defrost heat loads related to estimates of the amount of moisture evaporating from product or entering through doorways.
- Possible or prospective process changes in the future.
- Change in heat load with seasonal changes in ambient conditions.

Section 4.1.2 gives further details on heat loads and ways to minimise them.

4.3.4. Select system configuration

The next consideration is the selection of the refrigerant (Section 4.3.5) and refrigeration system configuration which are highly interdependent.

System configuration possibilities include:

- Direct use of the primary refrigerant or use of a secondary coolants in all applications. Use of a secondary coolants allow the primary refrigerant system to be isolated in an plant room and have a low refrigerant charge, which might allow highly efficient but flammable and/or toxic refrigerants to be used safety and with lower capital cost.
- Direct expansion, flooded evaporator or pump circulation. Direct expansion systems tend to have lower capital cost and lower refrigerant charge but also tend to have lower efficiency particularly due to poorer evaporator performance relative to flooded or pump circulation systems. Flooded systems are well suited to systems using secondary coolants. Pump circulation systems are best suited if there are multiple refrigerated applications across a large site that to be provided by a central system and it is deemed that use of secondary coolants would be significantly less efficient.
- Single-stage or multistage. If temperature lift and hence the compressor pressure ratio (PR) is not too high, then single stage will probably be adequate. For high temperature lifts, or if refrigeration is required at different temperature for different applications, then multistage is often more cost-effective.

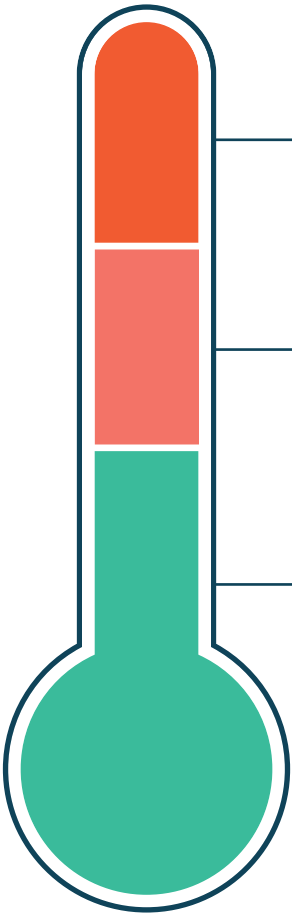
- Cascade systems. Multi-stage systems can be configured as a cascades of separate single stage systems or as an integrated, directly interconnected multi-stage system. Cascaded systems allow different refrigerants to be used so the refrigerants can be better matched to the required temperatures and the safety requirements. For example, CO_2 is a very good low temperature refrigerant and is safe for direct use in applications where people are present, whereas many other high efficiency refrigerants are toxic and/or flammable. Cascade systems potentially incur a penalty due to the extra temperature difference in the cascade heat exchanger, but this is compensated by the refrigerants chosen for each part of the cascade being better matched to the operating conditions.
- Multiple separate refrigeration systems or a single centralised refrigeration system. Separate refrigeration systems allow independent operation but probably have higher capital cost. A centralised system may be cost-effective if there are multiple applications with complementary load profiles over time or if secondary coolants are used to deliver refrigeration to applications.
- Economized/vapour injection/parallel compression. For some scroll and most screw compressors there is an economiser/vapour injection suction port which can be connected to a suction at intermediate pressure to the main compressor suction and discharge pressures. If such a port is connected to an economiser flash vessel or an economiser heat exchanger it allows two stage expansion of the refrigerant which reduces flash gas generation in the expansion valve and therefore gives more cooling capacity and higher energy efficiency (often 10-20% increases depending on refrigerant and operating conditions). Parallel compression provides the same benefit but requires a separate compressor on the intermediate pressure suction.

The use of common compressor suctions for a number of refrigerated applications rather than separate suctions should be carefully considered as lowered suction pressure contributes to a reduction in energy efficiency. With a common suction, all of the refrigeration is performed at the efficiency of the application requiring the lowest suction. If there is a significant difference in required evaporation temperature between applications, then configuring the refrigeration system with separate suctions allows the higher temperature applications to be refrigerated more energy efficiently but may increase the capital cost (separate piping, compressors and controls for each suction).

A range of systems are available for any specific application. Refrigeration owners should request that their suppliers offer alternative systems with a cost/benefit analysis of each so that the most appropriate one can be chosen.

Efficient compressor operation requires that the pressure ratio (PR) be kept low. Therefore, low temperature applications require more complex refrigeration systems, and these are broadly summarised in Table 7. Appendix A provides a more comprehensive discussion of compressor types.

Table 7: Suggested compressor arrangements by temperature stacks



Application Temperature Requirement	System Type	Compressor Type
Above -10°C	Single Stage	Economised or parallel compression optional
-10°C to -20°C	Single Stage economised	Screw or scroll (reciprocating if parallel compression)
-20°C to -50°C	Two Stage or Cascade	Economised or parallel compression high stage optional Screw, Reciprocating or Scroll

4.3.5 Refrigerant selection

Medium to large scale refrigeration systems normally have design lives of at least 15 years, so the choice of refrigerant should be future focussed. The type of refrigerant can affect the efficiency of a system by up to 10% as well as having safety and environmental impacts. Table 8 summarises the characteristics of the main refrigerants used for refrigeration. It should be noted that all refrigerants are asphyxiants and all refrigeration system operate at pressure significantly greater than atmospheric pressure, so system integrity to minimise leakage and good servicing practices for safety are key priorities. In addition, many refrigerants are flammable, toxic or operate at very high pressures requiring additional safety precautions (Section 4.3.6). Currently, other than natural refrigerants (NRs), most refrigerants suitable for larger scale refrigeration applications will be mixtures of HFOs and lower GWP HFC refrigerants (refrigerant mixtures are given numbers in the R400 or R500 series).

The phaseout of CFC and HCFC is now largely complete. There are a few R22 systems still being operated but they are usually scheduled for conversion or replacement over the next few years. Due to their high Global Warming Potential (GWP), a schedule for phasedown of HFCs has just been introduced under the Kigali Agreement amendment to the Montreal Protocol. HFC imports reduce towards 15% of 2011-13 usage by 2035. In addition, the purchase of refrigerants requires corresponding purchase of carbon credit units under the Emissions Trading Scheme (ETS). This will significantly add to the price of higher GWP refrigerants (e.g. those containing HFCs). For example, for an ETS carbon unit price of \$50/tonne CO_2 equivalent, then the price for R404A which as a GWP of 3922 increases by nearly \$200 per kg of refrigerant.

HFO refrigerants are starting to be used as part of low GWP refrigerant mixtures to replace HFCs. However, HFOs are mildly flammable and most mixtures including HFOs suitable for larger scale refrigeration systems will have at least one of the following disadvantages:

- Moderate GWP due to HFC content and therefore increased cost via the ETS and reduced availability due to the HFC phase-down.
- Mildly flammable due to high HFO or R32 content (A2L safety classification).
- Large temperature glide (glide is a temperature change that occurs during evaporation of condensation due to different volatilities of the mixture components). Glides greater than about 2K significantly affect refrigeration system design and may reduce energy efficiency.

Further, phaseout of HFOs is being considered internationally because they are PerFluoroAlkyl and PolyFluoroAlkyl Substances (PFAS). PFAS's are persistent in the environment (e.g. in drinking water) and have concerning environmental and health impacts.

The combination of the above factors means that for new facilities, it is risky to consider use of synthetic refrigerants including HFCs or HFO refrigerants. Therefore, refrigerant choice for industrial sized systems is effectively restricted to natural refrigerants (NRs). All NRs have good thermodynamic and transport properties that give high rates of heat transfer and low pressure drops. They are all high energy efficiency refrigerants if used in appropriate temperature ranges.

Of the NRs, carbon dioxide (R744) has the least safety concerns and is suitable for direct use in applications where people work (small leaks can be easily detected via low-cost CO_2 sensors and large leaks will result in formation of dry ice). It is an efficient refrigerant at low temperatures but is less efficient when rejecting heat to the ambient because its low critical temperatures of 31°C means that it usually operates in transcritical mode if the ambient temperature is above about 27°C. Therefore, it is a good choice as the low stage refrigerant in a cascade or as an evaporating secondary coolant.

Ammonia (R717) remains a good choice for many larger scale systems. It is a very efficient refrigerant across a very wide temperature range but it is toxic, mildly flammable (B2L safety classification) and incompatible with copper. The disadvantages of ammonia can be minimised by using it in combination with a secondary coolant or as the higher stage of a cascade (e.g. with CO_2 as the low stage in the cascade) so that the ammonia system will be both low charge and isolated in the plant room. For low temperature applications, such as process freezers or frozen storage, then a CO_2/ammonia cascade may be appropriate (an extra consideration is that a leak in the cascade heat exchanger will form ammonium carbonate which is a solid so duplicate cascade heat exchangers are recommended to ensure continuous operation). For medium temperature applications such as process chillers or chilled product storage, then a glycol secondary coolant and an ammonia primary refrigeration system may be appropriate.

Hydrocarbons (HCs) are also efficient refrigerants across a wide temperature range but are highly flammable (A2 safety classification). Therefore, their use in medium to large scale system should normally only be considered in conjunction with a secondary coolant such as glycol or CO_2 so that charge level can be minimised, and the HCs can be isolated to a highly protected plant room. Another option is to have multiple HCs systems operating in parallel; each with a charge well below the limits set in safety standards[5]. Isobutane (R600a) is less suitable for low temperature applications, while propane (R290) can be used for most temperatures.

A study into the most appropriate type of refrigerant for your needs should be undertaken as it can have major effects on all of capital cost, safety and energy efficiency.

For existing systems using HFC refrigerants, then an option to reduce costs and decarbonise if the refrigerant leaks, is to retrofit with a lower GWP refrigerant. Unfortunately, very low GWP refrigerants suitable for “drop-in” retrofits of refrigerants like R404A (GWP = 3922) are not currently available nor are they likely to become available. The best alternatives include R407C, R407F, R452A, R448A and R449A, R449C or R470B. However, these refrigerants all require some system changes (e.g. elastomers, expansion valves, heat exchanger circuiting) and therefore are not true drop-in replacements. Further, all have intermediate GWPs between 720 and 2100 so while the effect of the ETS on price is mitigated, they do not represent full decarbonisation. Very low GWP alternatives to HFC refrigerants are nearly always mildly flammable and often have very large glides, so they are not suitable for retrofit to an existing system designed for a non-flammable and low glide refrigerant (such as R404A). Further, changing to alternative HFC refrigerants is unlikely to improve energy efficiency and often may incur a slight energy penalty.

For existing systems using HFC refrigerants, the above factors mean that all of the following may be necessary to allow the system to reach its normal end of life while avoiding very high costs for refrigerant charge top-ups:

- Extra maintenance to find and repair or prevent sources of leakage.
- Changing to HFC refrigerants with intermediate GWP.
- Refrigerant stockpiling when availability is high, and prices are lower.

Table 8: Characteristics of refrigerant groups

Refrigerant Group	Examples	Uses	Issues
ChloroFluoroCarbons (CFCs) (generally A1 safety class)	R12, R502	Widely used until phased out in 1990s via Ozone Layer Depletion Act	Ozone depletion (Montreal Protocol)
HydroChloroFluoroCarbons (HCFCs) (generally A1 safety class)	R22	Widely used until 1990s and phased out by 2015 via Ozone Layer Depletion Act	Ozone depletion (Montreal Protocol)
HydroFluoroCarbons (HFCs) (generally A1 safety class)	R134a, R404A, R407C, R407F, R410A, R417A, R422D, R448A, R449C, R450A, R466A, R507, R513A, R32 (A2L)	Widely used since 1990s as replacements for CFC and HCFCs. To be phased down to 15% of 2011-13 use by 2035	Global Warming (Kigali Agreement); high GWP Require different oils than CFCs or HCFCs High temperature glides for some lower GWP mixtures
HydroFluoroOlefins (HFOs) (generally A2L safety class)	R1234yf, R1234ze, R1366mzzz(E)	Increasing use as HFC replacements (often in mixtures)	Mildly flammable Expensive High temperature glides for many mixtures Restrictions as PFASs increasingly likely
Hydrocarbons (HCs) (A3 safety class)	R600a (iso-butane), R290 (propane), R1270 (propylene)	Increasing use in low charge systems as HFC replacements	Flammable
Natural Refrigerants (NRs)	R717 (ammonia), R744 (CO_2), HCs	R717 has been widely used industrially since the 1890s R744 used prior to 1950s and revitalised since 2010's.	R717 is toxic, mildly flammable (B2L classification) & reacts with copper R744 operates at very high pressures R744 is less efficient operating transcritical

4.3.6 Safety considerations

Designing for energy efficiency must not compromise safety. There are a number of aspects to safety for a refrigerated facility including:

- Safe design and operation of the refrigeration system due to all refrigerants being asphyxiants and operating at high pressures, and some refrigerants also being flammable, toxic or operating at very high pressures.
- Design of the refrigeration system and buildings to address seismic and other natural hazard risks.
- Personnel safety related to working at refrigerated temperatures and in the vicinity of machinery such as forklifts (see worksafe.govt.nz for general requirements).
- If respiring products are being stored, the risk that oxygen and CO_2 levels could get too low or too high respectively (e.g. use sensors to detect oxygen and CO_2 levels that activate alarms and/or ventilation if levels become dangerous).

In terms of refrigerant and refrigeration system safety, then the key regulations are:

- Health and Safety at Work (Hazardous Substances) Regulations 2017.
- Health and Safety in Employment (Pressure Equipment, Cranes and Passenger Ropeways) Regulations 1999.
- Electricity (Safety) Regulations 2010.

For industrial refrigeration systems, these regulations require compliance with AS/NZS 5149:2016 (Parts 1–4) Refrigerating systems and heat pumps – safety and environmental requirements.

4.3.7 Select the secondary coolant (if secondary loops are used)

The advantages of using a secondary coolant distribution system include:

- Using a secondary fluid separates potentially dangerous refrigerants from food processing areas and working areas.
- Secondary coolant distribution systems can often be significantly lower cost than distribution systems for primary refrigerants (e.g. PVC piping for glycol rather than cooper or steel piping for primary refrigerants).
- The primary refrigerant is isolated to the refrigeration plant room only. Therefore, the primary circuit is very compact which minimises refrigerant charge, leak detection and repairs are more easily undertaken, and pipework is shorter, so pressure drops are reduced, which all help make such systems safer and more efficient.
- Secondary coolants can provide tight temperature control of the refrigerated application with low-cost controls.
- Leaks of secondary coolants are less dangerous and are normally easier to detect and repair.
- Storage of the coolant allows load shifting (Section 4.2.3.4).

The disadvantages of secondary coolant systems include that:

- A higher temperature lift is required for the primary refrigerant cycle, due to extra temperature difference in the heat exchange between the primary refrigerant and the secondary coolant.
- The pumping power for circulation of the secondary coolant can be significantly higher than for circulation of a primary refrigerant.
- Poorer performance of application cooling heat exchangers due to sensible heat transfer only and poorer transport properties for many secondary coolants relative to primary refrigerants.

Where use of a secondary coolant is proposed, there are a number of features and properties that need to be considered when selecting the coolant. The coolant should:

- Be compatible with the materials in the distribution system.
- Be safe and low cost.
- Allow satisfactory heat transfer and reasonable pressure drop at the low temperature they will operate so evaporator performance and pumping power do not become significant constraints.

For example, at temperature below – 20°C then the required flowrates and viscosity of brines and glycols become sufficiently high that coolants such as CO_2 become more attractive (lower mass flowrate due to latent rather than sensible cooling and lower viscosity). Further discussion of secondary coolants is provided in Section 4.2.1.11.

4.3.8 Select evaporators and condensers

Condenser and evaporators (including heat exchangers between secondary coolants and the application) should be sized to maintain the lowest practical condensing temperature and the highest effective evaporating temperature – key considerations in any whole-system design approach.

Other design factors include:

- Specifying cowlings for fans to improve air distribution over heat exchange surfaces and to improve fan efficiency.
- Using high efficiency fans and motors as standard features.
- Locating evaporators and condensers to ensure no impediment to flows of air or ambient coolant and to minimise heat gains
- Provision of drip trays and defrost water removal systems for air cooling evaporators to prevent spillage on floors and consequent ice build-up.

4.3.8.1 Evaporators in direct cooling systems

Evaporator types and defrosts methods for air cooling evaporators are described in Appendix A. The cooling capacity of the evaporator is determined by the size and design of the evaporator and the difference in temperature between the process/product being cooled and the evaporating refrigerant. The wider the temperature differences between the process/product/secondary coolant and the refrigerant, the greater the rate of transfer of heat. A larger evaporator heat transfer area will generally be able to achieve higher evaporation temperatures, and hence higher system efficiencies. The design of the evaporator should be chosen for the specific application.

For direct expansion systems, more advanced expansion valves such as electronic expansion valves (EEVs) should be used to ensure stable operation and hence good evaporator performance when the head pressure is varying.

Refrigerant superheat at the evaporator exit should be minimised to less than 5ºC above the evaporating temperature (e.g. through use of EEVs for direct expansion systems or use of flooded evaporators). The temperature difference between the application and the evaporation temperature must be greater than the degree of superheat, so selecting an evaporator for a low temperature difference but operating it with a high superheat is counter-productive and will result in lower than intended evaporation temperature.

The most efficient defrost method should be selected given constraints on water availability and capital costs. Defrost controls should allow optimisation of initiation and termination as discussed in Section 4.2.1.2.

4.3.8.2 Condensers

Types of condenser are described in Appendix A. A lower condensing temperature results in lower compressor energy use. The lowest possible coolant temperature provides potential for the condensing temperature to be lower (e.g. bore water or wet bulb temperature for water cooled or evaporative condensers rather than dry bulb temperature for air-cooled condensers). The more surface area a condenser has, the closer the condensing temperature is to the temperature of the coolant, whether ambient air or water. Best practice design takes a balanced approach toward capital cost, water consumption and energy use, particularly taking into account the ambient temperature and humidity. Controls should enable the condensing (head) pressure to 'float' with ambient temperature to take advantage of cooler ambient temperatures as discussed in Section 4.2.1.3.

4.3.9 Select compressors

As the compressor is usually the greatest consumer of energy in the refrigeration system, it is important to choose the most efficient compressor for the purpose and the load. Types of compressor are described in Appendix A. Two key parameters for selection are the:

- Full load efficiency at both the design conditions and the typical operating conditions. This is usually expressed by compressor manufacturers as COP or electrical power (kWe) per cooling duty (kWr) which is the reciprocal of COP.
- Part-load efficiency, if the compressor is to run for long periods at less than full load. This is usually expressed as a percentage of the full load efficiency (Figure 4) or change in the kWe per kWr.

No typical efficiency values for compressors are provided as compressor performance very much depends on system configuration and operating conditions. However, in general terms, open drive compressors tend to be slightly more efficient than semi-hermetic compressors because of economies of scale and, for the latter type, the motor cooling is performed by the refrigerant rather than ambient air.

For screw compressors, external rather than liquid injection oil cooling should be selected (Section 4.2.1.7) and the volume ratio (Vi) of the compressor should be selected to match the pressure ratios (PRs) likely during operation. Low Vi screws are suitable for low stage (booster) suctions with low PR whereas higher Vi screws are better suited for high stage suctions or single stage systems with higher PRs. If condensing temperature is varying significantly with ambient conditions, then automatically variable Vi screws should be selected so the compressors efficiency remains optimal as the head pressure floats.

Reciprocating or scroll compressors are generally well suited for small to medium sized loads whilst suction with larger loads often incorporate reciprocating, screw or centrifugal compressors. Screw and scroll compressors allow an economised/vapour injection cycle to be used (Section 4.3.4).

In terms of part-load performance, then VSD speed control is preferred for all types of compressor due to the low penalty, followed by cylinder unloading for reciprocating compressors, and with slide valve unloading of screw compressors having the least efficient part-load efficiency (Figure 4 and Section 4.2.1.5).

4.3.10 Heat recovery

If the site has a significant net need for heating at temperatures less than 100°C then heat recovery and or heat pumping should be part of the refrigeration system design. The main heat recovery and heat pumping opportunities are described in Section 4.2.3.

If heating is required over a range temperatures starting below 30°C and ending above 60°C (e.g. potable water heating), then a transcritical CO_2 heat pump may be a viable option. The characteristics of CO_2 and the transcritical cycle enable such a heat pump to simultaneously do the heating across a wide temperature range and provide refrigeration at less than 0°C using a single stage system (other refrigerants using normal sub-critical cycles would require two-stage systems to achieve similar overall energy efficiencies).

As described in Section 4.2.3.5, use the roofs of refrigerated buildings as sites for photovoltaic panels is also often a very cost-effective option to be considered as part of the design of a new refrigerated facility.

5

Selecting a service provider

Upgrading and improving your refrigeration system can take considerable time depending on your circumstances. While you may want to follow the steps in this guide, you may not have the time or resources available to do so. Refrigeration service providers can supply the services required to assess, upgrade or install your refrigeration system. You may wish to ask them to assist you with some or all of the process. In either case, there are some questions you should ask before you begin.

Will the provider take a systems approach?

It is important that your service provider considers how to optimise your entire refrigeration system, not only one or two of its components. In your tender documents you should specify that the lowest life cycle cost will be used in decision making and your expected rate of return on investment or whatever other economic criteria will be used (for example, simply payback, internal rate of return). Consider including performance criteria that will reward the contractor for reducing demand and for proven energy efficiency. Ensure that the provider will include the following in their investigation if asked:

- Minimisation of cooling duty
- Control system optimisation
- Refrigerant selection
- Choice of refrigeration system configuration
- Refrigerant leak management assessment
- Optimisation of pressure and temperature levels used in the system
- Heat recovery and/or heat pumping potential.

Will the provider examine the demand-side as well as the supply-side?

While the cooling supply-side equipment such as the compressor, condenser, expansion valve and evaporator are important considerations, the provider should also be investigating the demand-side of your system, including the refrigerant or coolant distribution network, temperature regulation, control of air and moisture ingress, minimisation of other refrigeration loads, the impact on refrigerated product quality, and the profile of the refrigeration demand over time.

What analysis services do they offer?

In order to ensure your refrigeration system runs as efficiently as possible, the provider must first conduct a detailed analysis of various aspects of your system. Your provider should also be able to measure and analyse the load profile of your system and the related power consumption to report on performance.

Other questions to ask of your provider include:

- What training do their staff have?
- Are they qualified to work on all refrigeration systems?
- Can they service and install equipment such as compressors, evaporators, condensers and piping?
- Do they provide an emergency service response? What are their guaranteed response times?
- Will they take care of parts shipping?
- Will they contract out any of the work themselves?
- Do they have the capability to remotely monitor your system?
- What training can they provide to your staff and operators?
- Are they able to advise on heat recovery or heat pumping options, and provide equipment for the identified opportunities?
- What is their track record on delivering energy-efficient refrigeration?

6

Glossary

coefficient of performance (COP)	A measure of the efficiency of a refrigeration system performance defined as cooling duty (kW)/input power (kW)
compressor	Device that accepts low pressure refrigerant vapour from the evaporator and compresses it to a higher pressure before it is sent to the condenser for heat rejection
condenser	Device for rejecting heat from the refrigeration system into the ambient. Hot high pressure refrigerant vapour loses its superheat and latent heat and condenses to become a warm high pressure liquid. It can refer to an air – or water-cooled heat exchanger or an evaporative-style unit that incorporates a fan and pumped water system
coolant	Secondary refrigerant used to transfer cooling energy created in the refrigeration system to other parts of the site where cooling is required
cooling duty	The amount of useful cooling being carried out by a refrigeration system (also known as refrigeration demand, cooling load or heat load)
cooling tower	A structure that provides water cooling through the partial evaporation of the water as it is sprayed over a packing surface and contacted with ambient air supplied by a fan. Usually associated with water-cooled condensers.
discharge pressure	The delivery pressure of the refrigerant from a compressor (also known as head pressure)
distribution system	A piping and pumping system that distributes the coolant into physical areas where cooling is required
dry bulb temperature	The temperature of the air measured by a thermometer protected from radiant heat gain and moisture accumulation and evaporation
energy balance	A method of analysis where the heat flows into and out of the bounded system being studied are added up together with the change in energy stored within the system. Energy can neither be created or destroyed, so the heat and energy flows into the system must equal the heat and energy flows out of the system plus the change in energy stored within the system. The bounded system can be a physical volume like a cold room, or a component within a coolant distribution system.

enthalpy	Total energy content including sensible and latent heat plus pressure effects
evaporator	Heat exchanger where refrigerant fluid is changed from liquid to vapour absorbing heat in the process
expansion valve	A valve that is used to reduce the pressure of the high pressure liquid refrigerant with minimal change in enthalpy. The pressure drop causes some of the liquid refrigerant to flash off as a vapour. The heat to form this vapour cools the remaining liquid refrigerant to the evaporator's operating temperature.
head pressure	The delivery pressure of the refrigerant from a compressor (also known as discharge pressure)
heat recovery	The process of recovering heat from any heat rejection part of the process or the refrigeration system for use in another part of the process such as preheating domestic hot water
HVDC link	The high voltage direct current transmission system connecting the electricity networks of the North Island and the South Island of New Zealand together.
mass flow rate	The rate at which a mass of fluid passes a given point in the process network, usually measured in kg per second
pressure-enthalpy diagram	Thermodynamic chart commonly used to represent a refrigeration cycle (also called a Mollier or P-h diagram)
pressure ratio (PR)	The ratio of the refrigerant absolute discharge pressure to the absolute suction pressure for a compressor
refrigerant	Fluid that is vaporised and condensed in the refrigeration cycle to achieve a cooling effect in part of the system.
refrigeration/or cooling load	The amount of heat that must be absorbed from an area to keep the process, product or space temperature within permissible limits (also known as cooling duty or heat load)
relative humidity	The moisture content (i.e., water vapor) of the atmosphere, expressed as a percentage of the amount of moisture that can be retained by the atmosphere (moisture-holding capacity) at a given temperature and pressure without condensation.
saturation temperature	The temperature at which a substance changes its state e.g., from liquid to vapour, liquid to solid and vice versa if heat is added or removed
solar gain	Heating of a process or area from exposure to sunlight

specific heat capacity	The amount of heat required to raise a kilogram of a given substance by 1°C
suction pressure	Pressure of refrigerant at the intake of the compressor
temperature lift	The difference between refrigerant condensing and evaporating temperatures in a refrigeration system.
thermal envelope	The structural components of a building that separate the inside from the outside, and prevent heat from transferring between the two.
variable-speed drive (VSD)	A control mechanism that can vary the speed of a pump, fan or compressor in response to measured parameters and control signals. They are usually electronic devices that change the frequency of the supplied electricity to effect a change in the motor speed.
wet bulb temperature	The lowest temperature that results when water evaporating into an air stream. It is related to the amount of moisture in the air and is equal to or lower than the dry bulb temperature of the air.

7 References

1 EECA Energy Use Database – https://www.eeca.govt.nz/insights/data-tools/energy-end-use-database/

2 Cleland, D.J., Cleland, A.C., White, S.D., Love, R.J., Merts, I., East, A.R., Wang, J.F., Paterson, A.H.J. (2024) Cost-Effective Refrigeration, Massey University, Palmerston North ISBN 0-908665-17-2.

3 Werner, S.R.L, Vaino., F., Merts, I., Cleland, D.J. (2006) Energy use by the New Zealand cold storage industry. Refrigeration Science and Technology Series 2006-1 p313-320 (Proceedings IIR-IRHACE 2006 Conference, Auckland, NZ, 16-18 February, 2006).

4 Pearson, A. (2022) Predicting specific energy consumption in the Southern Hemisphere, Paper 192, Proceedings 15th IIR-Gustav Lorentzen Conference on Natural Refrigerants, Trondheim, Norway 13-15 June 2022.

5 AS/NZS 5149:2016 Refrigeration Systems and Heat Pumps – Safety and Environmental Requirements (parts 1 to 4); also ISO 5149, EN378 and ASHRAE 15.

6 ISO 14040:2006 Environmental management – Lifecycle assessment – Principles and framework

7 http://www.turbocor.com/literature/pdfs/product_literature/TurbocorProductBrochure.pdf

8 Health and Safety at Work (Hazardous Substances) Regulations 2017 – https://www.legislation.govt.nz/regulation/public/2017/0131/latest/whole.html#DLM7309401

9 Health and Safety in Employment (Pressure Equipment, Cranes and Passenger Ropeways) Regulations 1999 – https://www.legislation.govt.nz/regulation/public/1999/0128/latest/whole.html#DLM284452.

10 Electricity (Safety) Regulations 2010 – https://www.legislation.govt.nz/regulation/public/2010/0036/latest/whole.html#DLM2763501.

The following are further sources that may be of interest.

11 I am your industrial refrigeration guide, Office of Environment and Heritage, 59 Goulburn Street, Sydney NSW 2000, Australia, https://www.energy.nsw.gov.au/sites/default/files/2022-08/2017_06_NSW_IndustrialRefrigerationGuide.pdf

12 https://www.sclaa.com.au/wp-content/uploads/2021/10/SCLAA_factsheet_No2_2040118.pdf

13 https://www.carbontrust.com/our-work-and-impact/guides-reports-and-tools/refrigeration-guide

14 https://www.sustainability.vic.gov.au/energy-efficiency-and-reducing-emissions/in-a-business/by-sector/energy-efficiency-in-manufacturing-food-and-beverage

15 https://hvacrcentre.nz/flammable-refrigerants-fact-sheets/

16 https://www.worksafe.govt.nz/about-us/news-and-media/technical-bulletin-ammonia-refrigeration/

17 https://www.worksafe.govt.nz/about-us/news-and-media/hydrocarbon-refrigerants/

18 https://www.eeca.govt.nz/regulations/equipment-energy-efficiency/about-the-e3-programme/products-under-e3/

19 https://www.genless.govt.nz/for-business/on-site/use-efficient-equipment/refrigeration/

20 https://www.eeca.govt.nz/co-funding-and-support/for-businesses/

21 https://coolsafe.org.nz/

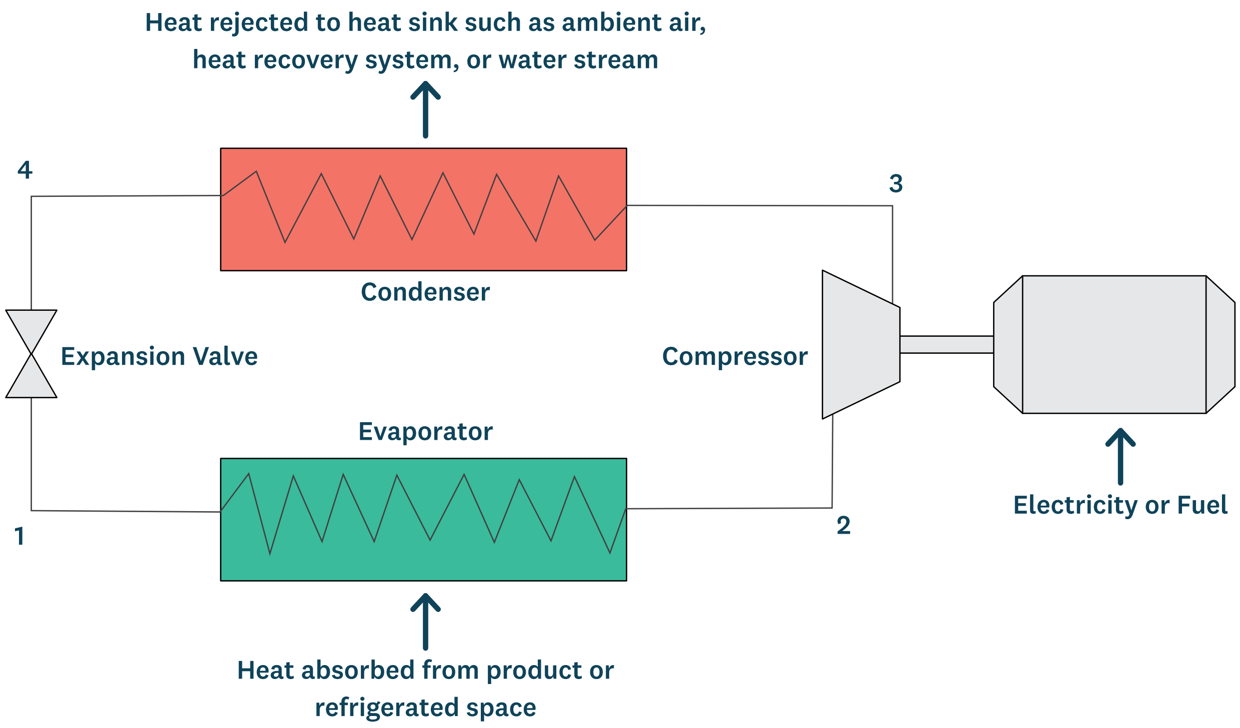
8 Appendices

Appendix A – Industrial Refrigeration System Overview

Several types of refrigeration cycles are used in industry, but the most common is known as a vapour compression cycle. Figure 6 shows the components of a typical single stage vapour compression refrigeration system and provides a simple explanation of how such a system works.

The basic components of a mechanical compression system include an evaporator, compressor, condenser and expansion valve. The heat transfer liquid (refrigerant) changes state from vapour to liquid throughout the vapour compression cycle stages as described below.

Figure 6: A typical single stage vapour compression refrigeration cycle



State 1: Cold liquid refrigerant at low pressure flows into the evaporator where the refrigeration cycle begins. In the evaporator, the liquid refrigerant is boiled off (evaporates) to become a cool low-pressure vapour by the heat of the product, space or coolant being refrigerated. The latent heat of evaporation for a refrigerant is large so relatively small refrigerant flowrates are required for a given cooling duty. The evaporation temperature of the refrigerant must be lower than what is being cooled, so it is usually between about 0°C and – 40°C (or even lower) depending on the application. The greater this temperature, the less energy the compressor will use.

State 2: The refrigerant is a cool vapour at low pressure, having just changed state from a liquid to a vapour after absorbing heat in the evaporator. The refrigerant vapour is then compressed to a hot superheated, high-pressure vapour by the compressor. Performing this compression is the main energy requirement of the refrigeration system.

State 3: The hot superheated, high pressure, refrigerant vapour discharged from the compressor enters the condenser where it will reject heat to the ambient environment (air and/or water). The heat rejection cools (de-superheats) the refrigerant to the condensation temperature and then condenses the refrigerant to become a warm high-pressure liquid. Typically, the condensation temperature should be at least 5-10°C hotter than the environment that heat is rejected to. The lower this condensation temperature, the less energy the compressor will use. The heat rejected in the condenser is approximately equal to the total of the heat absorbed by the refrigerant in the evaporator plus the energy added during compression. After the condenser, most systems have a liquid receiver that acts as a buffer to changes in the amount of refrigerant in the various parts of the cycle as operating conditions vary.

State 4: The refrigerant leaves the condenser as a warm liquid at high pressure. It will then pass through an expansion valve, which drops the pressure and “expands” the refrigerant into a cold, low-pressure liquid. Depending on the system configuration and operating conditions, in the expansion valve a fraction of the low-pressure liquid evaporates to a vapour which further cools the fraction that remains as a liquid. After the expansion valve, the refrigerant is back at State 1 and ready to begin the refrigeration cycle again.

In industrial situations, the refrigeration cycle can be used in two ways:

- Directly – refrigerant is directly connected to the cooling load (for example, a process cooling heat exchanger, a coil in a tank or an air-cooling evaporator).
- Indirectly – refrigerant cools a secondary fluid or coolant like water, glycol or brine to ‘transfer’ the ‘cooling energy’ to the cooling load via a distribution network.

Cycle and system performance

The coefficient of performance (COP) measures the performance of the refrigeration system and is calculated by dividing the cooling duty (the amount of cooling being carried out) by the power input (the amount of energy required to achieve the cooling):

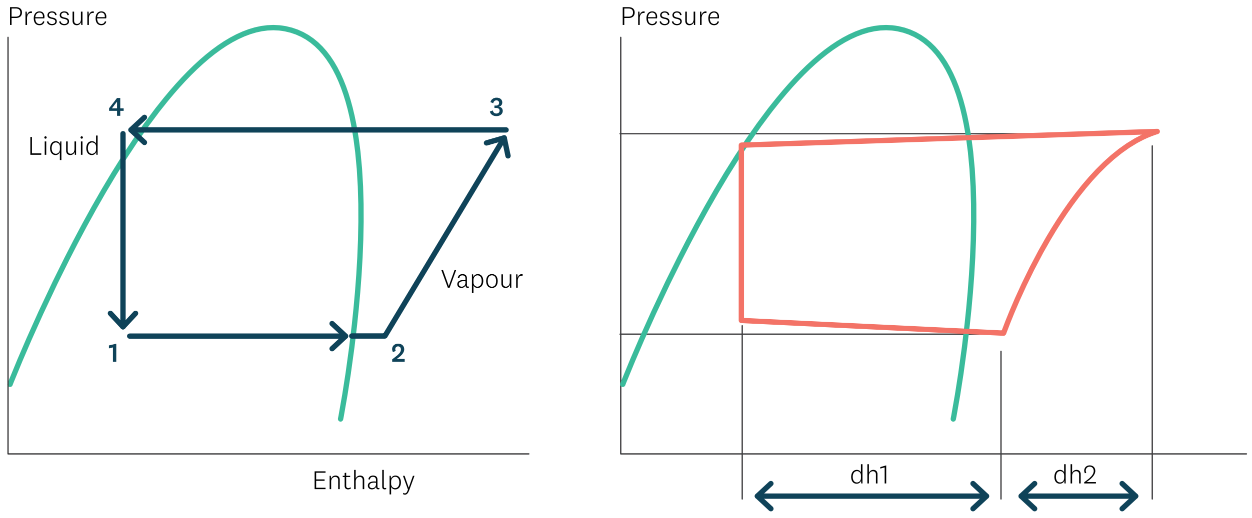
COP = cooling duty (kW) / power input (kW)

When COP is calculated, commonly only the compressor power input is included and often the COP is calculated only when the compressor is fully loaded at the design condition and not averaged over a year of operation (such a COP is often referred to as the compressor COP). Alternatively, a system COP can be calculated that includes the power input to fans, pumps and controls as well as to the compressor, plus it may take into account the part-load operation of the refrigeration system as cooling duty varies throughout the year. Generally, system COPs are lower than compressor COPs because the later do not include all the power inputs and take account of part-load system performance. Thus, care must be taken when comparing COP values from different sources to ensure that you are comparing like with like (i.e. COP values have been calculated the same way and for the same operating conditions).

A refrigeration system with a high COP under common operating conditions is a good starting point for designing an energy efficient system. Although refrigeration system manufacturers can accurately measure and quote the refrigeration system COP for the system over a wide range of conditions, the end user should ultimately be concerned with optimising the total system COP over a typical production schedule, as this will determine the cost of supplied refrigeration energy. Taking a whole-system approach is the best way of achieving energy-efficiency gains and represents industry best practice.

A pressure-enthalpy diagram, as illustrated in Figure 7, is a common means of representing the cooling duty and work done in the refrigerant cycle. The compressor COP can be thought of as the enthalpy change in the evaporator (dh1) divided by the enthalpy change in the compressor (dh2). Simply, an efficient system minimises the work done by the compressor (dh2), and maximises the heat removed through the evaporator (dh1).

Figure 7: Common refrigeration pressure-enthalpy diagram showing a single stage cycle



9

System components

Evaporators

Refrigerant in liquid form first passes through an expansion valve, dropping in pressure and temperature, and then enters the evaporator where it ‘boils’ into vapour and chills the air or liquid flowing past the tubes.

Evaporators come in many forms including:

- Shell and tube or plate heat exchangers for cooling liquids.
- Fin and tube heat exchangers for cooling air.
- Heat exchange coil in tank.
- Jacketed vessels (evaporation occurs on the external wall of the vessel).

Air cooling evaporators also require a defrost system if they operated with air temperatures below about 5°C. The common defrost systems are:

- Electric – electric elements embedded in the coil. Low capital cost but high energy use.
- Hot gas – compressor discharge gases are “reverse cycled” so the evaporator becomes a condenser. High capital cost but low energy cost.
- Water – large quantities of water are sprayed over the evaporator surface. Moderate capital cost but high water use and risk of “water/ice falls” into the refrigerated space
- Hot glycol – the evaporator has a tube circuit through which hot glycol heated by heat recovery is recirculated. Moderate capital costs and low energy costs (glycol pumping).
- Air – the evaporator is closed off from the refrigerated space and ambient air is blown over the evaporator. Moderate capital cost and low energy costs (fans) but leakage through the air control dampers can be difficult to avoid.

Compressors

Compressors are usually run by an electric motor and are the main power consumers in refrigeration. The compressor is the driver of the refrigerant flow around the refrigeration cycle and serves two main functions:

- To compress low-pressure refrigerant vapour to a higher pressure (and therefore higher condensation temperature) so that heat can be rejected to the ambient in the condenser.
- To remove refrigerant vapour from the evaporator to maintain a low evaporation temperature (and therefore low temperatures for the product, space or coolant).

The performance of a compressor is highly dependent on the pressure ratio, PR (ratio of discharge to suction pressure). In general, compressor efficiency decreases as PR increases, but efficiency can also be low at very low PRs.

There are different types of compressors including:

a) Reciprocating. Compression is via a piston reciprocating in a cylinder analogous to a car engine. Reciprocating compressors come in a wide range of sizes but are generally limited to PR less than 8. Some multi-cylinder compressors can part-load by depressurizing each cylinder (i.e. a four cylinder compressor can operate at 25%, 50% or 75% or 100% of full load). Some reciprocating compressors have head cooling via water jackets. Small capacity reciprocating compressors tend to be semi-hermetic whereas larger scale are open drive.

b) Twin screw. Intermeshing male and female screws draw in and then compress the refrigerant as the volume trapped between the screws increase at the suction and decreases at the discharge as the screws rotate. Screw compressors can operate across a very wide range of PR and are part-loaded via a slide valve that allows internal vapour by-pass. The location of the suction and discharge ports can change the volume ratio (Vi) for a screw compressor. For any PR there is an optimum Vi for maximum energy efficiency. Some screw compressors have fixed Vi whereas other can be manually or automatically adjusted. Screw compressors generally have high refrigerating capacity but high speed “mini-screws” are also available for smaller cooling duties. Most screws require oil cooling for long term operation. Screw compressor normally have an economiser port part way along the compression path that can be used for economised/vapour injection operation. Most screw compressors are open drive.

c) Mono-screw. Similar to twin screw compressors except that compression is by a single screw rotating into a “star” wheel (more balanced bearing loads).

d) Rotary vane. Compression is via changes in volume of sections of an elliptical body separated by off-centre sliding vanes that rotate. Rotary vane compressors are generally less efficient than other types and only suitable for high loads at lower PRs. Unloading is often by hot-gas bypass which is very inefficient.

e) Scroll. Suction and compression are due to change in the volume between two eccentric spiral scrolls as they rotate. Scroll compressors are generally semi-hermetic, have some capacity control by displacing the scrolls, and may have a vapour injection port as for screw compressors. As for reciprocating compressors they are limited to moderate PRs.

f) Centrifugal. Centrifugal compressors compress by converting high velocity into pressure head. They have very limited in the PR they can operate against and are generally used for large scale water chilling. Multi-stage centrifugal compressors are starting to be available for other refrigeration applications and allow oil-free operation by using magnetic bearings.[7]

All of the above compressor types can be speed controlled as an alternative to the other load control methods. Figure 4 compares the part-load efficiency for the various control types. Speed control is usually the most efficient way to control capacity while slide valve control for screws or hot gas bypass are the worst.

Twin screw and reciprocating compressors are most commonly used in industrial situations in New Zealand.

Condensers

Condensers reject heat from the refrigeration system to a heat sink such as the ambient air or water and come in many types including:

- Air-cooled condensers in which fans blow ambient air through the condenser which is normally a fin and tube heat exchanger.
- Water-cooled condensers in which water from a bore, stream/river, sea or a cooling tower is pumped through the condenser which is normally a shell and tube or plate heat exchanger. Cooling towers typically have a high surface area packing over which water is sprayed. Simultaneously air is blown up through the packing by fans. The water is cooled by evaporation of a fraction of the water into the air stream. Demisters minimise water droplets leaving in the air stream. The cooled water is collected in a basin from which it is recirculated.
- Evaporative condensers in which both water and air are circulated over tubes containing the refrigerant (essentially a combined cooling tower and tubular heat exchanger where fans blow air over the wetted tube surfaces to maximise the evaporative cooling effect).

Table 9 summarises the features of the main condenser types. So-called Adiabatic Condensers are evaporative condensers where the risk of Legionella is minimised by arranging the evaporative cooling process such that there is lower risk of sprays and aerosols forming into the discharged air stream.

Air-cooled condensers are generally used for smaller systems and the condensation temperature is a limited by the dry bulb temperature of the ambient air. Water-cooled and evaporative condensers provide the opportunity to operate at lower condensing temperatures as water sources are often colder than the ambient air (e.g. from bores). In particular, cooling tower and evaporative condensers approach the wet bulb temperature of the ambient air, thereby providing potential for improved energy efficiency of the refrigeration cycle. The fan and/or pump power consumption plus water use and water treatment associated with their operation should be considered during the selection process. Many water-cooled condensers will be used in combination with a cooling tower to reduce water use. If so, the combined net effect is similar performance and the same advantages/disadvantages as evaporative condensers.

Evaporative and air-cooled condensers and cooling towers are controlled by varying the air flow (turning fans on/off or using VSDs). Water-cooled condensers are controlled by varying the water flow.

Table 9: Characteristics of the main condenser types

Condenser Type	Energy Consumption	Advantages	Disadvantages
Air-cooled	Fan power Higher compressor power due to higher head pressures	Uses ambient air Low maintenance No water consumption No spray drift No risk of Legionella Unaffected by high humidity environments Low cost	High fan power Approaches air dry bulb temperature so higher head pressure leading to lower COP
Water-cooled	Circulating pump power Fans power if associated cooling tower	More efficient heat transfer Approaches water temperature or air wet bulb temperature so lower head pressure leading to higher COP Lower water use if used with cooling tower Low cost if no cooling tower	Higher maintenance especially if cooling tower used (e.g. water treatment) High water consumption Risk of Legionella if cooling tower used (including legislative compliance)
Evaporative	Circulating pump power Fans power	Most effective in low humidity environments Approaches air wet bulb temperature so lower head pressure leading to higher COP Lower water use than water-cooled without cooling tower	Higher maintenance (e.g. water treatment) Risk of Legionella (including legislative compliance) Higher refrigerant charge Higher cost

Expansion valves

The function of expansion valve is to reduce the pressure of the refrigerant before it enters the evaporator and to control the flowrate of refrigerant into the low-pressure part of the refrigeration cycle.

The different types of expansion valves depend on the configuration of the refrigeration system including:

- Thermostatic expansion valves (TEV) use pressure feedback via a superheat bulb filled with refrigerant to modulate refrigerant flow so that the refrigerant exiting the evaporator is superheated above the evaporation temperature by 6 to 8 K (direct expansion systems). The superheat ensures no liquid refrigerant can arrive at the compressor suction. The performance of such valves is sensitive to changes in system head pressure (sensitivity lower for balanced port designs).
- Electronic expansion valves (EEV) use electronic feedback from measurement of the temperature at the evaporator exit to control refrigerant flow so that the refrigerant exiting the evaporator is superheated above the evaporation temperature by 2 to 4 K (direct expansion systems). The superheat ensures no liquid refrigerant can arrive at the compressor suction. The performance of such valves are much less sensitive to changes in system head pressure than thermostatic expansion valves.
- Float valves and level switches control the level of refrigerant in intercoolers or separator vessels (flooded or pump circulation system) so that refrigerant entering evaporators after the vessels are 100% liquid and refrigerant leaving the vessel in the compressor suction line is 100% vapour.
- Hand expansion valves act as flow balancing valves to control the distribution of liquid refrigerant between multiple evaporators (pump circulation systems).

For direct expansion systems, expansion valve performance has a considerable influence on the performance of the whole refrigeration system. Lower refrigerant superheat at the evaporator exit improves evaporator performance giving higher cooling capacity and/or allowing higher evaporation temperatures to be used. Expansion valves that are insensitive to change in head pressure allow condensation temperature (head pressure) to be floated to lower level when ambient conditions are cooler (particularly for air-cooled condensers). Higher evaporation temperature and lower head pressures both results in lower compressor refrigerant discharge temperature (less compressor deterioration) and lower compressor energy use. For example, up to 20% savings have been demonstrated from the use of EEVs over TEVs.

Fans and pumps

Fans and/or pumps are essential for most refrigeration systems. Efforts should be taken to reduce pressure drops for the required fluid flows. For air flow, this includes use of large diameter ducting (if required), air turning vanes for tight bends and fan inlet and outlet air diffusers where they can be fitted. For liquid flow, this includes use of large diameter piping, a minimum number of and low head valves, a minimum of bends and minimising pipe run lengths.

The pump or fan characteristics should be matched to the required fluid flow and pressure drop and high efficiency pumps and fans should be selected. For example, a high efficiency fan will have aerodynamically shaped blades and a tight fitting and aerodynamically shaped cowling (and not just a simple angled sheet metal blades and a "hole" in a metal sheet for a cowling or no cowling at all).

Motors and drives

Motors and drives for many fans, pumps and compressors are separately supplied (e.g. open drive compressors) but also often come as part of an integrated package (e.g. semi-hermetic compressors, fans and motors pre-mounted on evaporators or condensers). It is important to consider the efficiency of drives in order to maximise energy savings. Motor and drive efficiency is also important for equipment that operates in refrigerated spaces (e.g. conveyors, forklifts, racking cranes and robots etc).

Direct coupled (shaft) drives have much lower power losses than belt drives or geared drives. They also have lower maintenance and so should be used if motors with the required speed for the application are cost-effective.

Many good energy-efficient motors are available, and VSDs should also be considered as they provide energy savings when installed as part of an overall control strategy and help to efficiently meet varying load demands. The efficiency of motors is particularly important where they are installed within refrigerated spaces because energy is used to both run the motor and to remove the heat that is delivered by the motor into the refrigerated space. For example, for smaller fans shaded pole motors are very cheap but often have energy efficiencies less than 40% whereas EC (electronically commutated) motors usually have efficiencies greater than 70% and also inherently allow speed control without having to buy a separate VSD.

Controls

To maintain correct operating conditions and optimize the efficiency of the refrigeration system, control systems are essential. In large systems, programmable computer controllers are generally used in conjunction with control switches, valves and regulators.

Secondary coolant distribution systems

Secondary or 'indirect' coolant distribution systems are becoming increasingly common in industry. Cooling is supplied throughout a plant by use of a secondary fluid or coolant. This distribution system utilises pumps, pipes, valves and controls. There are many system designs for pumped systems with various impacts on controllability, system response times and efficiency. Pipes should be sized to minimise coolant pressure drop as well as available surface area through which heat gain can occur. Flow balancing valves or orifices in each of the multiple feed lines help control and distribute the coolant.

Heat transfer fluids (coolants)

Transfer fluids, also known as secondary refrigerants, absorb heat via heat exchangers from heat loads distributed around a site and bring it back to the primary refrigeration system where the fluid is cooled again ready for re-circulation. Most secondary coolants do not undergo a phase change (sensible cooling/heating only) so high circulation flowrates are required to keep temperature change in the coolant low. Heat transfer fluids include salt brines such as calcium chloride and potassium formate (e.g. TEMPER), propylene glycol (non-toxic), ethylene glycol (toxic), and many other heat transfer fluids (e.g. ethanol/water mixtures). Higher glycol or brine concentrations are required to operate at lower temperatures but at higher concentrations and lower temperatures, the transport properties are less favourable, so rates of heat transfer are lower and pumping power increases. Commonly, a coolant mix of water with at least 20% glycol and corrosion inhibitors is used.

For applications requiring cooling at about 0°C, a relatively new concept is a pumpable ice-water slurry. Often low concentrations of salt are added to "soften" the ice, so it is easier to generate in a scraped surface heat exchanger. The slurry remains pumpable up to about 40% ice fraction and absorbs heat at a near constant temperature due to the latent heat of the ice melting. Due to the latent heat effects, ice slurry has a very high energy-carrying capacity (MJ/kg) so lower slurry flowrates are required compared with sensible heat coolants.

Carbon dioxide, which is a natural refrigerant with very low overall environmental impact, can be used as a secondary coolant as well as a primary refrigerant. The CO_2 is circulated as a liquid and return as a vapour, so the latent heat of evaporation is available for cooling (an evaporating secondary). The returning CO_2 vapour is condensed in the primary refrigerant system evaporator to complete the secondary loop. CO_2 circulation can be achieved by pumps or thermosyphon loops. Due to the high latent heat and the very favourable transport properties for CO_2, the circulation flowrates required are very low, the pumping power is very low, and the heat transfer rates are very high relative to other secondary coolants.

The selection of the secondary refrigerant will largely depend on the application for which it is intended and the refrigerant's properties relating to:

- Glycol/brine concentrations or pressures required for the desired temperature range
- Thermal and physical properties that affect required circulation flowrates, rates of heat transfer, and pumping power
- Stability over the temperature range and pressures to which it will be subjected
- Corrosiveness and material compatibility
- Toxicity.

NOTE: *most three-phase electric motors must be tested and registered for their energy efficiency and rated output. This helps ensure that end-users are buying suitably performing products, as they may be in operation, and using considerable amounts of energy, for many years. All motors must meet a specified minimum efficiency at 75% or 100% of their rated load. The registration list also includes details of which motors are designated as 'high efficiency'. Details, and a comparison of different models available, can be found on EECA's website and the Energy rating website. You can also find further information about new electric motor technologies on EECA's website. Over time, as technology improves, so does EECAs requirements, and new standards for electric motor performance are intended to be adopted in the future. This will align with standards overseas.*

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Appendix B – Life cycle assessment

Business decisions are generally made on the basis of costs. Life Cycle Costing (LCC) is the term used for this purpose. It is the sum of all the costs associated with procuring, owning, operating, maintaining and disposing of an item. The cost is appropriately discounted using techniques like Net Present Value to enable competing items to be compared.

It is the role of regulators to ensure that LCC results in business decisions that are environmentally valid by ensuring that environment costs become business costs. The most common technique to incorporate environmental impacts into an investment decision is to undertake a Life Cycle Assessment (LCA). LCA techniques were developed due to the increased awareness of the importance of environmental protection, and the possible impacts associated with products, both manufactured and consumed. LCAs can assist in:

- Identifying opportunities to improve the environmental performance of products at various points in their life cycle
- Informing decision makers in industry, government or non-government organisations (for example, for the purpose of strategic planning, priority setting, product or process design or redesign)
- The selection of relevant indicators of environmental performance, including measurement techniques
- Marketing (for example, implementing an eco-labelling scheme, making an environmental claim, or producing an environmental product declaration).

LCA addresses the environmental aspects and potential environmental impacts (such as use of resources and the environmental consequences of releases) throughout a product's life cycle from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal (that is, cradle-to-grave). It can also be applied to provision of services.

There are four phases in an LCA study[6]:

- The goal and scope definition phase – the scope, including the system boundary and level of detail, of an LCA depends on the subject and the intended use of the study. The depth and the breadth of LCA can differ considerably depending on the goal of a particular LCA.
- The inventory analysis phase – the life cycle inventory analysis phase (LCIA phase) creates an inventory of input/output data (resources and materials used and created) with regard to the system being studied. It involves collection of the data necessary to meet the goals of the defined study.
- The impact assessment phase – the life cycle impact assessment phase (LCIA) provides additional information to help assess a product system's life cycle impact so as to better understand their environmental significance. For example, if CO_2 emissions factors are known for each material or resource used then a carbon footprint could be estimated for the product or service being analysed.
- The interpretation phase – the findings from the inventory analysis and the impact assessment are combined, or, in the case of the life cycle inventory studies, the findings of the inventory analysis only, consistent with the defined goal and scope in order to reach conclusions and recommendations.

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Appendix C – General maintenance checklist

Logging the refrigeration system performance will help identify changes in performance over time. The maintenance schedule should be obtained and checked to ensure the following is being undertaken:

Regularly:

- Check the temperatures of cold rooms. Investigate the distribution of temperatures within the cold room, checking for hot or cold spots.
- Check evaporator and condenser coils for dirt or debris and clean them if required and comb the fins if they have become damaged.
- Regularly check the entire piping system, especially joints, seals, valves and glands for leaks.
- Check the refrigerant sight glass for bubbles. Bubbles in the sight glass often mean a system is leaking. Find the leaks and repair them before the system is recharged with refrigerant.
- Refrigerant top-ups should only need to be undertaken annually. When charging a system, air should be purged. Automatic purging systems should be considered if the system is regularly operating in a vacuum at the compressor suction.
- Report and repair any vibrating pipe work, as this is likely to cause a leak over time.
- Check that compressor oils are at the right level.
- Check that product is not impeding the evaporator air flow (if applicable). Also investigate the distribution of air flow with the cold room, it should be even to minimise temperature variability.
- Ensure that motors and belt drives have sufficient air circulation for cooling.
- Check for plugged line filters.
- Check evaporators are fully defrosting and that drain pan lines are clearing properly.
- Report ice on the floor and walls of cold rooms as this indicates that excessive air is entering the room, which becomes a defrosting and safety problem as well as adding to the cooling duty.
- Check all insulation of pipes, valves and process cooler or freezers for condition and appropriate thickness.

Monthly:

- Check compressor motor temperatures and ensure they are operating as recommended by the manufacturer.
- Check and treat cooling water entering and recirculating within the system. Remove scale, corrosion and biological growth as this can impede heat transfer.
- Check all oil pump and compressor joints and fittings and all relief valves in the system for leaks.
- Particularly for R717 systems, drain oil from evaporators or oil pots, if it is not automated.

Annually:

- Check the compressor motor assembly and lubrication system to ensure it is operating at maximum efficiency.
- Clean evaporator and condenser tubes and other heat transfer surfaces during a shutdown.

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