

# Energy Efficiency Best Practice Guide Industrial Refrigeration

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# 1 Introduction

This document is a step-by-step guide to improving energy efficiency in medium to large-scale industrial refrigeration systems for industry. It provides best practice information on system operation and outlines opportunities for improving system performance and efficiency, which will lead to benefits for your business.

By following this guide, you will be able to determine what changes can be made in order to improve the performance of equipment, reduce operating costs and improve environmental outcomes. Using refrigeration loads to minimise peak demand energy costs is not covered in this document.

The guide has been developed to lead decision makers and service providers through system changes; it is not intended to be a thorough technical guide. References for more detailed technical information are provided.

## 2 The business benefits of efficient refrigeration

Refrigeration systems consume large amounts of electricity and thereby contribute greatly to the running costs of businesses with considerable cooling requirements. In industry, refrigeration can be responsible for up to 85% of total energy consumption, depending on the industry sector, as shown in Table 1. Improvements to technical elements of modern refrigeration systems have the potential to reduce energy consumption by 15%–40%. Improving simple operational practices with minimal expense can often reduce energy costs by 15% or more. This will become more important as a price is placed on greenhouse gas emission in future years and as energy prices rise. Its importance also relates to an increased focus on reducing fugitive emissions from industrial systems such as refrigerant gas<sup>1</sup>.

**Table 1: Typical refrigeration-related electricity use.<sup>2</sup>**

Industry Sector	Electricity Used for Refrigeration
Liquid milk processing	25%
Breweries	35%
Confectionery	40%
Chilled ready meals	50%
Frozen food	60%
Cold storage	85%

Energy efficiency can deliver a range of savings, such as:

- reduced energy costs
- reduced operation and maintenance costs
- improved system reliability
- improved safety
- increased productivity
- better matching of refrigeration load and equipment capacity
- a better working environment
- reduced resource consumption and greenhouse gas emissions<sup>1</sup>.

Money saved on power bills improves the bottom line, meaning it can be of greater value than increased sales. For example, if a company had a gross margin of 10%, then saving \$1 in operational costs is like achieving \$10 in additional sales revenue.

## 3 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 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 of your refrigeration system.

- **Solution 1: Improve the efficiency of your existing system**

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

- **Solution 2: 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 analysis of existing systems should be undertaken to determine when it is viable to replace it. (Refer to Appendix B for how to conduct a life cycle analysis).

Are you expanding your premises and need to ensure that your refrigeration system will work effectively? This will involve elements of both solutions. Firstly, ensure your existing system is running efficiently (Solution 1) and secondly, if your system needs to be expanded, design the new components (Solution 2). Following this process will ensure that you are not wasting money purchasing more than you actually need. Additionally, information gained from reviewing efficiency may guide the selection and design of the new components of the system.

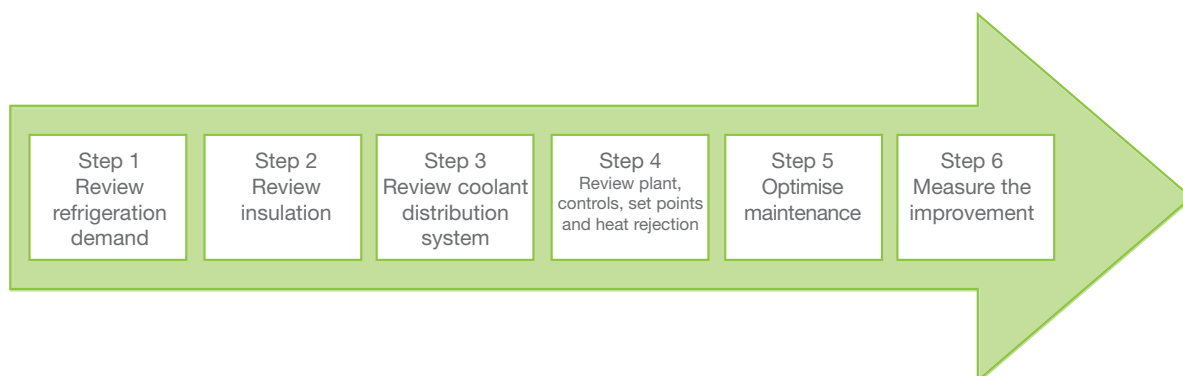
## 4 Solution 1 – Improve the efficiency of your existing system

Often, a refrigeration system runs inefficiently because the current system requirements differ 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 disrupted shutdowns are extensively avoided.

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.

A suggested process to follow when designing a new refrigeration system is as follows:



## 4.1 Step 1: Review refrigeration demand

### 4.1.1 Assess the cooling load

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

- what your theoretical refrigeration load should be
- which processes dominate your cooling energy consumption
- which refrigeration load temperature needs can be grouped together, with potential benefits to your central system operation.

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

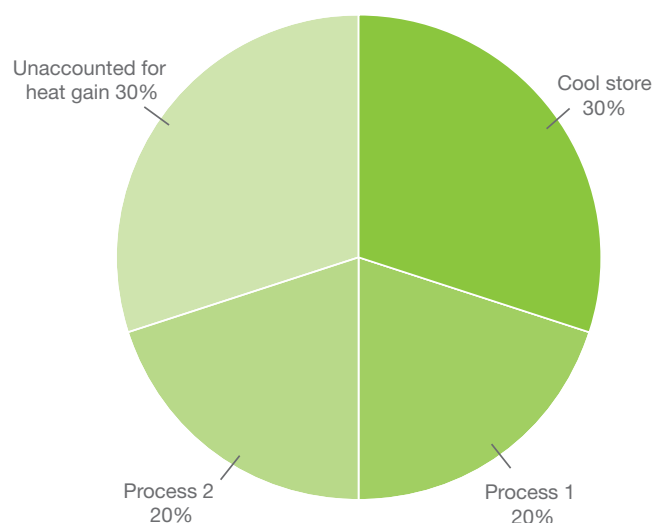
- poorly situated and uninsulated pipework
- heat exchangers
- poorly sited refrigeration equipment
- walls, floors and ceiling of a cool room
- air infiltration through doorways
- internal fan motors and pumps
- lights and other electrical devices
- people and handling equipment (such as forklifts).

It is often difficult to estimate how much heat is being gained from the environment; an energy 'balance' may assist you:

1. Calculate/estimate all theoretical cooling loads at the heat exchanger, cool store or process where the refrigeration load is occurring.
2. Calculate/estimate the refrigeration energy provided by the centralised system.
3. The difference between these two numbers would be 'unaccounted for heat gain'.

Figure 1 represents a typical energy balance for a cool store and two other refrigeration processes in which the system is providing 30% more refrigeration energy than the load demands.

Figure 1: Cooling energy balance.





### Creating a high-level energy balance for the refrigeration system

1. Identify all major process-cooling loads through looking at equipment manuals, process specifications and theoretical energy consumption for your process. This may not be perfect, but it will help you target your investigation.
2. Investigate the major cooling loads in more detail through measuring the volumetric flow rate of secondary coolant (if used), temperature rise of the coolant, and its specific heat capacity.
3. As an alternative to step 2, measure the heat flows from your product (for example, by using the mass flow rate, specific heat capacity and temperature changes of your product instead of the coolant).
4. Ideally, use data-loggers for flow rates and temperature rises, but 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 70% of all loads).

Your refrigeration supplier can assist you in doing this process, as they often need to estimate cooling loads.

### 4.1.2 Reduce heat gain

Potential solutions for reducing heat gains into a system 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.
- Increase insulation on pipework and avoid hot areas.
- Ensure process equipment is operating correctly and look for unexpected heat gains (for example, pasteurisers).
- Ensure product or spaces are not overheated to begin with.
- Reassess whether cooling is required at all, or raise the temperature of the coolant if possible.
- Reduce solar gain (provide shading).
- Place cooling equipment as far as possible from heat sources such as radiators and air-conditioning equipment.
- Minimise air infiltration into a cooled space.
- Install more efficient (especially internal) fan motors.
- Install more efficient pumps and turn off when not required.
- Reduce time personnel spend in (or passing through) cool areas – improve layout if possible.

#### 4.1.3 Reduce the cooling load

Some common cooling load issues are summarised in Table 2. By addressing these, you will also be improving the efficiency of your refrigeration system.

**Table 2: Cooling load issues.<sup>2</sup>**

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

**Table 3: Cooling load issues.<sup>2</sup>**

Symptom	Problem	Measure
Product being cooled below required temperature	Product temperature too low	Check temperature control system  If possible, raise the coolant temperature
Heat load in a cold store higher than expected; ice build higher than expected	Excessive heat and moisture ingress through cool store doors	Improve door closing 'discipline' Check door seals, airlock, strip curtains
Evaporator fans or pumps run when product has reached target temperature	Excessive auxiliary power	Ensure control systems maximise possibilities to switch auxiliaries off or reduce their speed
Cool store temperature too low	Incorrect control	Adjust thermostat
Cool store temperature too high	Inadequate cooling	Check that load is not too high (for example, doors left open, excessive warm product load) Ensure evaporators are defrosted. Check refrigeration plant performance (for example, control system problem, fouled heat exchangers)

## 4.2 Step 2: Review insulation

Uninsulated or poorly insulated coolant pipes can absorb heat from their surroundings. This has many negative effects and can seriously affect performance of the refrigeration system. For example:

- System heat gain means that the suction temperature of the evaporator is higher than necessary (increased energy consumption in the compressor).
- It could lead to process conditions not being reached (product quality failures).
- It could lead to higher brine/coolant flows (higher pumping energy).

Insulation should also be regularly inspected for moisture ingress, as this can form ice on the pipework, further damaging any insulation.

## 4.3 Step 3: Review the coolant distribution system

### 4.3.1 Distribution system

The energy involved in pumping transfer fluids around a system can be a big energy waster.

This means you should:

- Check if you are using the most appropriate secondary cooling fluid for your requirements (that is, pump the least amount of fluid practical; consider using fluids with a high heat capacity).
- Check that your pump system flexibly responds to variable refrigeration loads, rather than using the same amount of energy irrespective of the refrigeration requirement.
- Check that your insulation is in good order.
- Check that you have large-diameter pipes to minimise pumping pressure.

The mechanical efficiency of the pump drives is also highly important, and energy-efficient motors or variable-speed drives could be used.

### 4.3.2 Adjustable and variable-speed drives on pumps

When applied to pumps in the coolant distribution system, more efficient flow control can be achieved by using adjustable-speed drives (ASDs) and variable-speed drives (VSDs) or installing multiple pumps. ASDs and 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.<sup>3</sup>

In pumping systems with variable flow rate requirements, ASDs and VSDs are an efficient alternative to throttling or bypass pumping control methods.

ASDs and VSDs save energy by varying the pump's rotational speed. Reducing the pump speed means less energy is imparted to the fluid and less energy needs to be throttled or bypassed. However, it should be noted that they do not save energy in applications that operate close to fully loaded most of the time, due to the lower efficiencies. Table 4 shows the potential savings from the installation of a VSD for a 5.5 kW and an 8.5 kW motor operating for 8000 hours per year. In these cases, payback can be less than three years.

	Energy Consumption 5.5 kW motor with no VSD	Energy Consumption 5.5 kW motor with VSD	Energy Consumption 18.5 kW motor with no VSD	Energy Consumption 18.5 kW motor with VSD
Annual Energy Use (kWh)	44000	35200	148000	118400
Annual Energy Cost	\$4,400	\$3,520	\$14,800	\$11,840
Annual Energy Saving		\$880		\$2,960
VSD Cost		\$1295		\$3,460
Payback		1.5 years		1.2 years

**Table 4: Savings due to installation of variable speed drives.<sup>4</sup>**

*Assumptions: 8000 operating hours per year; 20% reduction in energy consumption due to VSD; electricity cost 10 cents/kWh.*

## 4.4 Step 4: Review refrigeration plant, controls, set points and heat rejection

### 4.4.1 Improve condensers and reduce head pressure

Evaporative condensers require water flow over tubes containing the hot refrigerant, and fans to move air through and help evaporate the water. Sometimes, fans on evaporative condensers run at a fixed speed and are scheduled to turn on and off based on a fixed condenser pressure setting.

The most efficient manner to run an evaporative condenser is to optimise it in conjunction with the compressor head pressure. Under this scenario, variable-speed fans may be installed on the condenser and they would be controlled in such a way to minimise head pressure on the condenser whilst not expending more energy than is saved in the process. The lower head pressure reduces energy consumption in the compressor, and the VSD fans enable variable airflows through the condenser whilst reducing the specific energy of providing that airflow.

### 4.4.2 Variable speed drives for evaporator and condenser fans

When VSDs are applied to condenser fans, typical operating cost savings are in the order of 2–3% of total refrigeration costs.<sup>5</sup> Variable-speed fans on air-based evaporators can also have a good return depending on operating conditions. Two-speed control is another good, although slightly less efficient, option. In both circumstances, the fan speed control should be linked to the compressor head pressure management system and ambient conditions.

### 4.4.3 Common compressor suction and discharge piping

Heat transfer is a function of area (amongst other things). So the greater the area, the more effective the heat transfer. In many systems, condensers are coupled directly to one compressor. It is more efficient to make the entire evaporative condenser capacity, or heat transfer area, available to the refrigeration plant at all times. This approach will minimise the head pressure on the compressor, improving the overall efficiency of the system.

### 4.4.4 Improve part-load performance

Compressor efficiency reduces considerably when run at partial loading. For a large cooling load, it is generally more efficient to split up the load between smaller compressors and run them in a way that minimises part-load operation for any individual compressor. An alternative is to implement a VSD on compatible compressors.

### 4.4.5 Add controls to operate compressors at highest efficiency point

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. It can also be assisted through larger evaporator or coolant storage systems.

#### 4.4.6 Compressor sequencing and control

Refrigeration systems can be operated automatically, semiautomatically, manually or by a combination of these. Of these, automatically computer monitored and controlled systems have the potential to operate the system at the greatest efficiency.

Some control issues are listed in Table 5 below.

**Table 5: Control systems issues.<sup>2</sup>**

Symptom	Problem	Measure
Product temperature low. Plant running even though target temperature achieved	Incorrect temperature controller	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	Check head pressure control settings and ensure they are set at lowest practical level

#### 4.4.7 Variable-speed compressors

VSDs may be applied to screw compressors, although energy savings may only be realised if changes are also made to the control of the internal slide valve, load sharing between the fixed and variable-speed compressors. The role of the variable-speed compressor would be to 'load-follow', with other fixed-speed compressors sharing the base load capacity. Your compressor manufacturer should be consulted before any retrofits, which may or may not be possible.

New types of compressors are also now on the market; one is an oil free, magnetic bearing, variable-speed, centrifugal compressor that was originally designed in Australia. Its full load coefficient of system performance (COP – refer to cycle and system efficiency in Appendix A for more information on COPs) of approximately 5.5 increases towards a COP of 12 at part load. It is most suited to water-cooled applications and can be retrofitted. Its higher efficiency is due in part to its very high rotational speed and use of magnetic bearings.

#### 4.4.8 Raise suction pressure

Refrigeration systems are most efficient when run at the highest possible suction pressure. Where evaporator pressure regulators are used on all loads, the suction pressure can be raised and can potentially improve compressor capacity by 2.5% for each degree of saturated suction temperature.<sup>5</sup> Efficiency increases depend on the starting point of your suction pressure increase, but improvements in the range of 2% for each degree increase in saturated suction temperature are possible.<sup>5</sup>

#### 4.4.9 Reduce temperature lift

Temperature lift is the difference between the evaporating and condensing temperatures. The importance of minimising lift requirements is essential, as a 1°C reduction in temperature lift can improve plant efficiency by 3–4%.<sup>6</sup> Temperature lift reduces if the condensing temperature is lowered and/or the evaporating temperature is raised. The COP of refrigeration systems is greater at lower temperature lifts.

#### 4.4.10 Reduce suction line pressure drop

If a direct expansion system is used (that is, refrigerant is sent out into your plant for direct use in vessels and heat exchangers), then it is important to minimise the pressure drop in the return line. This is because, from the perspective of the compressor, a large pressure drop will mean the effective suction temperature is lower than necessary, impacting on system efficiency. Consider larger refrigerant return pipes or a secondary cooling fluid.

#### 4.4.11 Floating head pressure control

It is possible to adjust head pressure in order to maintain an optimum heat-rejection temperature with regard to the ambient or wet-bulb temperature. This is a more efficient practise than fixing the head pressure at the maximum required to provide refrigeration on the hottest days.

#### 4.4.12 Reduce parasitic loads

Eliminate heat gains to your system. Visual inspection and thermal imaging can help identify 'hot spots'. Efficient fan and pump motors also save electricity. This is often a very cost-effective measure of improving your refrigeration efficiency and is a key example of a system-level approach.

#### 4.4.13 Convert from liquid injecting oil cooling to external cooling

Screw compressors often require oil cooling and it is quite common for them to use liquid injection oil cooling. Converting from high pressure, liquid-injection, oil cooling screw compressors to external (thermosiphon or fluid-cooled) oil coolers can give savings of over 3%.<sup>5</sup>

#### 4.4.14 Heat recovery at oil coolers

It is possible to recover a small amount of waste heat from the compressor oil coolers for activities such as domestic hot water, boiler feed water pre-heating and so on. Where there are suitable loads, and heat recovery does not lower system efficiency, heat recovery represents industry best practice.

## 4.5 Step 5: Optimise maintenance

### 4.5.1 Overview

If the refrigeration system is older than 10 years, it should be considered for replacement, since this may increase efficiency by up to 30% to 40%.<sup>7</sup> A life cycle cost analysis (refer to Appendix B) should be undertaken to assess this.

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 pressure drops 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 Section 6. Changes and repairs should be undertaken by qualified personnel.

### 4.5.2 Improve evaporator maintenance and defrosting

Evaporators assist the transfer of heat from a cooled space into the refrigerant so that heat can be released externally. A defrost cycle is often used to free evaporator coils from ice, to ensure maximum heat transfer and energy efficiency. Different defrost cycle control strategies have widely varying impacts on energy efficiency, bearing in mind that the heat used to achieve the defrost should be minimised since it enters the refrigerated space. Defrost should ideally be initiated when detectable loss of performance is evident. Airflow sensors and thermocouples can stop the defrost system as soon as the ice has melted to ensure maximum energy efficiency is achieved. A control system with evaporator 'defrost on demand' is the best system and defrosting should stop as soon as the evaporator fins are clear of ice.

Excessive ice might indicate that a drain is blocked or that the unit is too close to the thermostat. Evaporator fans should be cycled by the control system such that they are only used when needed. Most evaporator faults create a heat transfer problem that in turn causes evaporator inefficiencies, which results in low compressor suction pressure.

**4.5.3 Improve condenser maintenance**

Maintaining an optimum condenser temperature is important for energy-efficient operation. Condenser temperature depends on the condenser size and condition as well as airflow, ambient temperature and non-condensable gas in the refrigerant.

Condenser faults include blockages and heat transfer problems. Air and other non-condensables in the refrigerant will increase the condensing temperature and lower the efficiency. High discharge pressures are caused by inefficient condensing, which further reduces system efficiency down the line. Table 6 presents maintenance measures that assist in condenser performance.

**Table 6: Condensor maintenance.**

<b>Air-cooled</b>	<b>Water-cooled and Evaporative</b>
Keep coils clean	De-scale tubes
Ensure fans running correctly	Maintain water quality
Shade condenser	Ensure fill (membranes) are clean and achieving an even distribution
Ensure all control working systems working	Maintain pumps and fans
	Ensure all control systems working

**4.5.4 Improve maintenance on expansion valves**

Expansion valve problems are generally caused by the valve being open or closed when it shouldn't be, increasing compressor head pressure. Electronic valves with direct expansion evaporators can reduce compressor head pressure, and can have a good payback – up to 20% in some situations.

**4.5.5 Improve 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.



## 4.6 Step 6: 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:

- condensing temperature at the inlet and outlet
- evaporator temperature at the inlet and outlet
- compressor pressure and temperature at the inlet and outlet
- power to the compressor
- ambient temperature
- brine temperature.

The second method is to do an energy consumption assessment. In this method, the current system baseline operating performance characteristics are logged for energy usage versus ambient temperature and load. This can then be used to compare to the design parameters, track changes to the plant operation as a whole, or parts of the system, and measure improvements. The total energy consumption is calculated, which is made up of:

- compressors
- auxiliary equipment (pumps and fans).

The overall energy efficiency of a refrigeration system can be difficult to measure, can vary dependent on the temperature lift required and can be difficult to conceptualise, as it is usually greater than one. The system COP is calculated by dividing the cooling duty (the amount of cooling being carried out) by the power input:

$$\text{COP} = \text{cooling duty (kW)} / \text{power input (kW)}$$

Power input includes the total consumption of all the components associated with the refrigeration system; that includes compressors, pumps and fans. A good 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 assess this against the actual chiller and system COP over time. Tracking specific refrigeration consumption and cooling energy under a range of conditions before and after the improvements are made gives a good indication of the savings that have been made. Some examples of COPs for different compressor types are presented in Section 5.3.

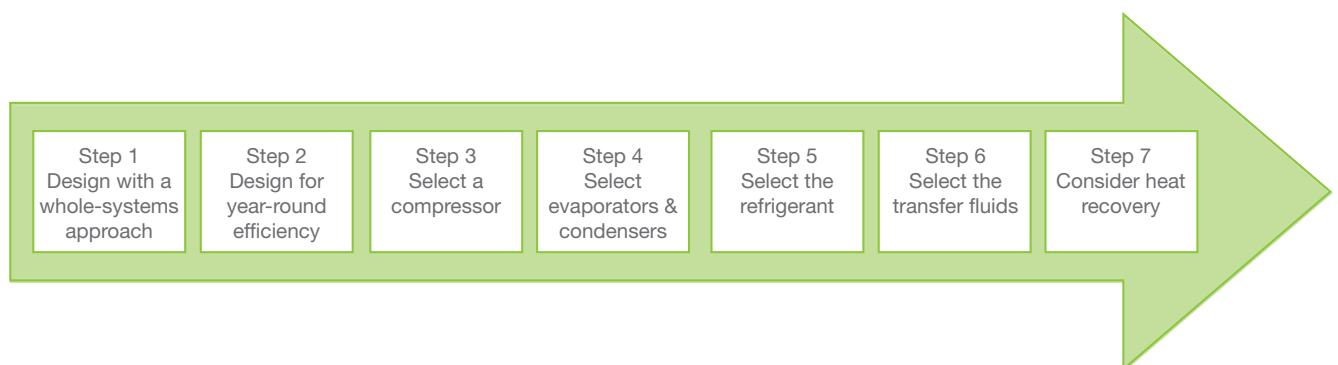
## 5 Solution 2 – Design a new system

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

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.
- Ensure designs minimise heat gain (for example, through efficient equipment, good pipe insulation) as described in 4.1.2 of Solution 1.

A suggested process to follow when designing a new refrigeration system is as follows



## 5.1 Step 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 1 also apply when designing a new system. Critically, a whole-system approach also continually evaluates how well the system design provides the necessary cooling function throughout the year and as the system is maintained over the course of its lifetime. Opportunities for enhanced heat recovery may also be identified when taking a whole-system approach during system design.

## 5.2 Step 2: Design for year round efficiency

Quite often, refrigeration systems are designed for the peak cooling demand (which occurs for less than 5% of the year<sup>8</sup>). That means the systems run for considerable periods at part load, which can be highly inefficient if incorrectly designed. A new system should be designed for efficiency at part-load performance over the entire year and still meet peak demand. Using a systemic approach, any designs should also consider minimising the thermal loads on the system in the first place.

A good way to assess the operating envelope is to develop a table of the existing or predicted cooling loads versus ambient temperature and the amount of time this occurs per year. Tenderers can then use this information to predict the energy consumption over the year.

## 5.3 Step 3: Select a compressor

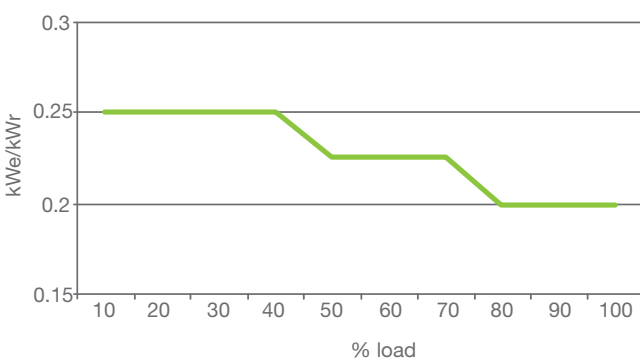
As the compressor is usually the greatest consumer in the refrigeration system, it is important to choose the most efficient compressor for the purpose and the load. Compressors have different properties – reciprocating compressors are generally used for small to medium-sized chillers whilst larger capacity chillers incorporate centrifugal or screw compressors. As a guide, the following are considered to be typical efficiency values at full-load operation:

**Table 7: Typical compressor efficiency values**

Reciprocating:	0.27–0.29 kWe/kWr (COP ~ 3.5)
Centrifugal (without VSD):	0.18–0.22 kWe/kWr (COP ~ 5)
Screw:	0.18–0.22 kWe/
Centrifugal (high speed with integrated VSD):	0.09–0.17 kWe/kWr (COP~ 5.5–10)

### 5.3.1 Reciprocating compressors

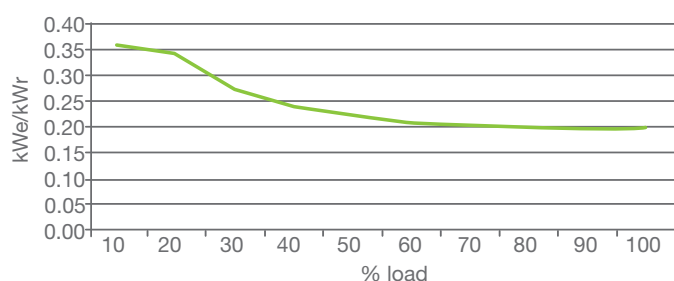
Reciprocating compressors are limited in size, generally to between 350 kW<sub>r</sub> and 1000 kW<sub>r</sub>, for economic reasons. A water chiller that incorporates multiple compressors can provide good staging in reduction of capacity. Figure 2 illustrates a typical energy consumption curve for a 3-stage reciprocating compressor.



**Figure 2: Typical energy consumption curve for a reciprocating compressor – inverse of COP<sup>9</sup>**

### 5.3.2 Centrifugal compressors

A centrifugal compressor is similar to a centrifugal pump and compresses refrigerant by spinning at high speeds. The capacity of a centrifugal compressor can be varied by a set of vanes at the compressor inlet to vary the refrigerant flow through the compressor. Capacity of centrifugal chilled water units would usually start at about 800–1000 kW<sub>r</sub> up to 4000 kW<sub>r</sub> or more. Figure 3 illustrates a typical energy consumption curve for a centrifugal compressor.

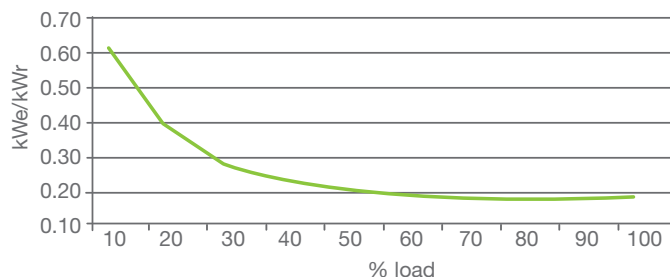


**Figure 3: Typical energy consumption curve for centrifugal compressor – inverse of COP.<sup>9</sup>**

A new high-speed compressor is an oil-free, magnetic bearing, variable speed centrifugal compressor that was originally designed in Australia. Its full load COP of approximately 5.5 improves remarkably at part load to over 10. It is most suited to water cooled applications, and can be retrofitted.

### 5.3.3 Screw compressors

A screw compressor tends to be more compact than an equivalent centrifugal compressor and operates with less vibration. Capacity is varied by a slide valve. Similar to centrifugal compressors, the screw compressor water chiller units commence at between 800 kW<sub>r</sub> and 1000 kW<sub>r</sub> capacity. Whilst screw compressors have traditionally operated more efficiently than centrifugal and reciprocating compressors, their part-load performance without a variable-speed drive is far worse. Figure 4 illustrates a typical energy consumption curve.



**Figure 4: Typical energy consumption curve for screw compressor – inverse of COP<sup>9</sup>**

## 5.4 Step 4: Select evaporators and condensers

Condenser and evaporators should be sized to maintain the lowest practical condensing temperature and the highest effective evaporating temperature – key considerations in any whole-system design approach. The use of common evaporator suction pipes and condenser pipework should be considered.

### 5.4.1 Evaporators

The cooling effect 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 and refrigerant, the greater the rate of transfer of heat.

A larger evaporator will generally be able to achieve higher evaporator efficiencies. The design of the evaporator should be chosen for the specific application. There are a number of types including:

- direct expansion coolers
- pumped liquid air coolers
- shell and tube liquid coolers
- plate heat exchanger liquid coolers
- boudelot liquid coolers.

To avoid inefficient use of the evaporator, superheating in the evaporator should be limited to 5°C above the evaporating temperature. When defrosting the evaporators, a defrost operation should be done using the most efficient method possible, only initiated when necessary to prevent a loss of performance, and stopped as soon as the fins are clear of ice. The best way to initiate defrosting is using sensors, an approach which is always more efficient than timers.

### 5.4.2 Condensers

The more surface area a condenser has, the closer the condensing temperature is to the temperature of the cooling medium, whether air or water. Lower condensing temperature results in lower energy consumption. Best practice design takes a balanced approach toward the consumption of water and energy, particularly taking into account the atmospheric temperature and humidity. Condensing pressure should be enabled to 'float' with ambient temperature to take advantage of cooler temperatures. When this floating is allowed to occur, more advanced expansion valves should be used (such as electronic).

## 5.5 Step 5: Select the refrigerant

Refrigerant selection is important, as the type of refrigerant can affect the efficiency of a system by up to 10%.<sup>10</sup> With the phasing out of fluorocarbon chemicals (CFC, HCFC), due to their detrimental effects on the environment, ammonia is still currently the dominant refrigerant for industrial refrigeration in Australia.<sup>11</sup> It is the least expensive of the common refrigerants, has good heat transfer properties in both liquid and vapour states – it is thermodynamically 3–10% more efficient than HCFC-22 and HCFC134a<sup>12</sup>

**Table 8:** Characteristics of refrigerant groups.<sup>13</sup>

Type	Examples	Uses	Issues
CFC	R12, R502, R11	Widely used up until 1990	Phased out due to ozone depletion issues
HCFC	R22, R409A, R411B	Widely used but not recommended after 1999	To be phased out by 2015 Stringently regulated
NH <sub>3</sub> (Ammonia)	R717	Widely used since the birth of refrigeration	Toxic in high concentration and flammable, also reacts with copper
HFC	R134a, R404, R407C, R410C, R507	Started to be used in place of CFCs from 1990	Different compressor oil required Some performance and reliability issues
HC (propane, iso-butane etc)	R600a, R290, Care 30, Care 50, R1270	R290 still used in some industrial systems Care 30 and 50 used commercially	Flammable
CO <sub>2</sub>		Used widely before the 1950s and is now being 'rediscovered'	High operating pressures require special materials and construction Toxic in high concentrations

A study into the most appropriate type of refrigerant for your needs should be undertaken, particularly given that refrigerant leakage can be highly toxic, have a large global warming and/or ozone-depletion effect, and leakage varies significantly by refrigerant type and application (for example, from <1% up to 40% per annum depending on the size and age of the system<sup>14</sup>). Refrigerant choice also affects the energy efficiency of chiller operation, and some refrigerants are to be phased out over the coming years (such as HCFC). Chillers with greater than 100 kg of refrigerant will need to be registered under the new Australian National Greenhouse and Energy Reporting Systems Policy.

Carbon dioxide (CO<sub>2</sub>) has recently been rediscovered as a good primary and secondary refrigerant. It has been successfully used in a number of large-scale storage and processing refrigeration plants around the world, including a new system in western Victoria, which is estimated to be saving 29% of its refrigeration costs compared to ammonia. Propane can also be used as a refrigerant, with similar efficiency to that of ammonia.

## 5.6 Step 6: Select the transfer fluids

Transfer fluids must be compatible with the materials in the distribution system. They should also be safe and economical to use. When subjected to the lowest temperatures in the system, the fluid should allow satisfactory heat transfer and reasonable pressure drop. The advantages of using a transfer fluid distribution system include:

- Using a secondary fluid separates potentially dangerous chemicals from food processing plant and working areas.
- The primary refrigerant is used in the refrigeration-plant room area only, which means leak detection and repairs are more easily undertaken. Less primary pipework also means that pressure drops are reduced.

The disadvantage of this type of system is that a higher temperature lift is required, due to loss in the heat exchange transfer with the secondary fluid.

## 5.7 Step 7: Consider heat recovery

Some heat recovery is possible from oil coolers on the compressor, superheat from the compressor or the system condenser. Many industrial processes require heat at a much higher temperature than the reject stream of the compressor, but if your process requires heat at less than 80°C, then heat recovery should be considered.

## 5.8 Summary of savings

Throughout the document, potential savings of energy have been noted and are summarised in Table 9. Whilst savings are not necessarily cumulative, this demonstrates the importance of whole-system approaches, which includes design, installation, operation, maintenance and periodic review.

**Table 9: Potential energy savings.**

Method	Potential Saving (Energy, unless otherwise noted)
Use of electronic expansion valves	20%
VSD on motors	20%
VSD on evaporator and condenser fans	2–3% of total refrigeration costs
Evaporator pressure regulators	2.5% greater compressor capacity for each degree of saturated suction temperature
Evaporator pressure regulators	2% for each degree increase in saturated suction temperature
Reduced temperature lift	3–4% improvement for 1°C reduction
Conversion from liquid injection oil cooling to external oil coolers	Over 3%
Refrigeration system replacement if older than 10 years	Up to 30–40%
Refrigerant selection	3–10%

## 6 Summary of design considerations for refrigeration systems

Table 10 summarises design considerations for components of industrial refrigeration systems.

**Table 10: Design considerations for efficient refrigeration systems.**

<b>System considerations</b>	<ul style="list-style-type: none"> <li>–Ensure a whole-system approach is used</li> <li>–Design for year-round efficiency</li> <li>–Avoid heat gain in the system by using ambient cooling, insulation, shading, minimising air infiltration and so on</li> <li>–Design for part-load performance using</li> <li>–VSDs on compressors or efficient staged compressor control</li> </ul>
<b>Evaporators</b>	<ul style="list-style-type: none"> <li>–Use automatically controlled (on-demand) defrost</li> <li>–Install drains for removing non-condensables from the evaporator</li> <li>–Use electronic expansion valves on smaller units</li> <li>–Raise evaporator pressure as far as possible and allow to ‘float’ higher when the refrigeration demand is low</li> <li>–Allow for easy cleaning</li> <li>–Consider VSDs for evaporator fans</li> </ul>
<b>Compressors</b>	<ul style="list-style-type: none"> <li>–Ensure you enquire about compressor efficiency (COP) over the range of expected loads</li> <li>–Use common compressor suction and discharge piping</li> <li>–Use VSDs where appropriate</li> <li>–Consider high-speed, magnetic bearing, variable-speed centrifugal compressors</li> <li>–Consider external oil coolers and heat recovery</li> <li>–Allow head pressure to ‘float’ to make the most of ambient conditions</li> </ul>
<b>Condensers and cooling towers</b>	<ul style="list-style-type: none"> <li>–Consider VSDs for condenser fans linked in with head compressor pressure control</li> <li>–Use a condenser with high surface area to achieve a lower condensing temperature, and hence lower energy consumption</li> <li>–Consider using evaporative condensers rather than cooling towers only</li> <li>–Link the control of the cooling towers to floating head pressure control to drive condensing water as cold as practicable</li> </ul>

<b>Expansion valves</b>	<ul style="list-style-type: none"><li>–Use electronic expansion valves where possible on small systems</li><li>–Link expansion valve control with head pressure controls</li></ul>
<b>Motors, drives, pumps</b>	<ul style="list-style-type: none"><li>–Use high-efficiency motors and drives</li><li>–Consider VSDs for loads that vary</li><li>–Use high-efficiency pumps and refer to the best practice guides on pumping system designs</li></ul>
<b>Controls</b>	<ul style="list-style-type: none"><li>–Use a control system that is responsive to compressor head pressure</li><li>–Aim to achieve highest possible suction pressure and lowest possible head pressure at all times, and reduced temperature lift</li></ul>
<b>Secondary distribution system</b>	<ul style="list-style-type: none"><li>–Insulate pipework</li><li>–Select a secondary cooling fluid with appropriately high heat capacity</li><li>–Use large-diameter pipes to minimise pumping pressure</li><li>–Use an energy-efficient system design</li></ul>
<b>Refrigerant selection</b>	<ul style="list-style-type: none"><li>–Use a refrigerant that is most appropriate for your needs, considering efficiency, toxicity, and ozone and greenhouse impact</li></ul>
<b>Maintenance</b>	<ul style="list-style-type: none"><li>–Institute an ongoing maintenance plan</li><li>–Train operators in maintenance for energy efficiency</li></ul>
<b>Service provider</b>	<ul style="list-style-type: none"><li>–Use a qualified, experienced service provider that takes a system approach, examining both refrigeration supply and demand</li></ul>



## 7 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. Ensure that the provider will include the following in their investigation if asked:

- control system optimisation
- refrigerant leak management assessment
- pressure levels throughout the system
- flow throughout the system
- heat recovery potential.

### **Will the provider examine the demand side as well as the supply?**

While the 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 distribution network, temperature regulation, the end uses and the profile of the demand.

### **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 the staff have?
- Are they qualified to work on all refrigeration systems?
- Can they service and install equipment such as compressors, evaporators, filters and piping?
- Do they provide emergency service response?
- 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?

## Appendix A

### Industrial refrigeration system overview

#### Refrigeration cycle overview

Several types of refrigeration cycles are used in industry, but the most common is known as a vapour compression cycle. Figure 5 shows the components of a typical 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 gas to liquid throughout the vapour compression cycle stages as described below.

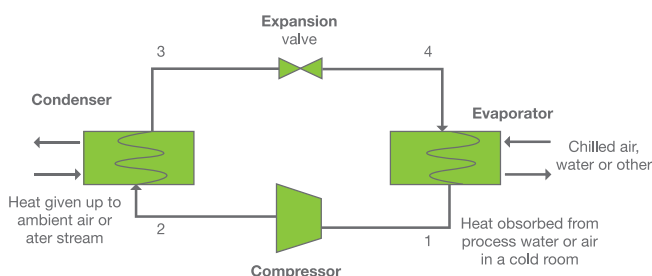


Figure 5: A typical vapour compression refrigeration cycle.<sup>10</sup>

**Stage 1:** The refrigerant is in a cold gaseous state, having just changed state from a liquid to gas after absorbing heat in the evaporator from the process (or air). A refrigerant in liquid form will absorb significant amounts of heat during evaporation – it is this phase change that enhances the cooling effect in the refrigeration process.

**Stage 2:** The gas is then compressed by the compressor and discharged as a hot gas. It enters the condenser where it releases its latent heat of evaporation to either water or air. The heat released is equivalent to the heat absorbed by the refrigerant in the evaporator plus the heat created by compression input.<sup>15</sup> In this stage, the refrigerant will become liquid again.

**Stage 3:** The refrigerant leaves the condenser as a hot liquid and then passes through the expansion valve, which expands the hot liquid into a cold liquid.

**Stage 4:** The cold liquid flows into the evaporator where the cycle begins again. The fluid is boiled off (that is, evaporated) to a cold gas by the heat of the product being refrigerated. The cold gas returns to the inlet (or suction) of the compressor.<sup>10</sup>

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

- Directly – refrigerant is pumped to the cooling load (for example, a process cooling heat exchanger or tank).
- Indirectly – refrigerant cools a secondary fluid like water, glycol or brine to 'transfer' the 'cooling energy' to a point of use on a distribution network.

### Cycle and system efficiency

There are two commonly quoted refrigeration efficiencies: the efficiency of the chiller subcomponent and the efficiency of the system as a whole. Efficiency is denoted as the coefficient of performance (COP) and is calculated by dividing the cooling duty (the amount of cooling being carried out) by the power input:

$$\text{COP} = \text{cooling duty (kW)} / \text{power input (kW)}$$

The theoretical COP of the chiller includes only the compressor power input at a nominal load, whereas a real 'as installed' system COP includes the power input to fans and pumps, and takes into account the part-load operation over time. The whole-system COP is therefore less than the chiller COP. The system COP varies with refrigeration temperature, heat rejection temperature, outdoor temperature and humidity, condenser type, pipe size and length, production profile, and many other factors.

A chiller with a high COP under common operating conditions is a good starting point for an energy-efficient system. Although chiller manufacturers can accurately measure and quote the chiller COP 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 6, is a common means of representing the work done in the refrigerant cycle. The COP can be thought of as the enthalpy change in the evaporator divided by the enthalpy change in the compressor. Without going into too much detail, an efficient system minimises the work done by the compressor, and maximises the heat transferred out of the process through the evaporator.

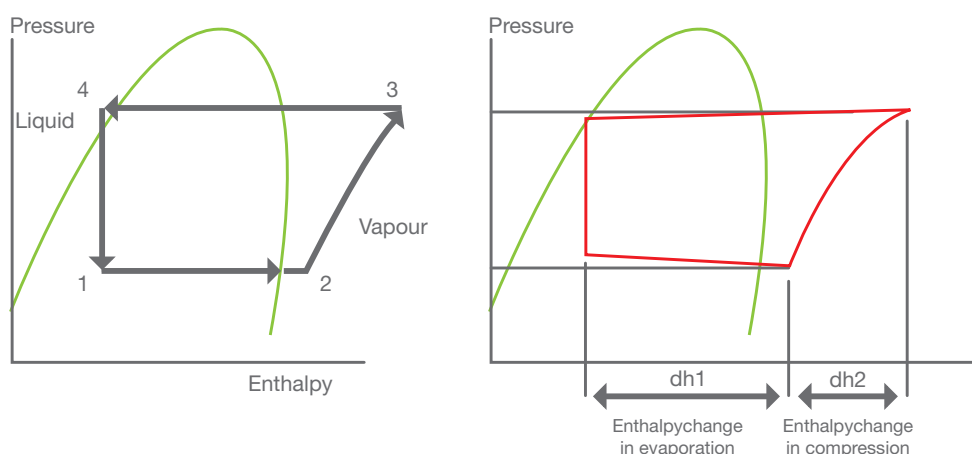


Figure 6: Common refrigeration pressure-enthalpy diagram.<sup>10</sup>

## System Components

### Evaporators

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

Evaporators come in many forms, for example:

- shell and tube or plate heat exchangers
- wet geo-fabrics
- coil in tank
- jacketed vessels where the evaporation occurs on the external wall of the vessel.

### 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 and serves two main functions:

- To compress low-pressure refrigerant gas to a higher pressure (and therefore higher temperature) so that heat can be more easily rejected.
- To remove vapour from the evaporator to maintain a low boiling point (and hence low temperature for cooling brine or process flows).

There are different types of compressors, including screw, centrifugal and reciprocating. More information is provided in Solution 2 on determining which type should be used. Screw compressors are most commonly used in industrial situations, but many sites also have reciprocating units.

### Condensers

Condensers reject heat from the refrigeration system and come in many forms, including:

- evaporative condensers (water and air is used in a cooling tower type arrangement for cooling the refrigerant)
- dry condensers (air is passed directly over the condenser)
- water-cooled condensers
- plate heat exchangers.

A comparison between the three main types of condensers is presented in Table 11

**Table 11: Condensor types.**

Condensor Type	Energy Consumption	Advantages	Disadvantages
Air-cooled	Fan power, higher compressor power input for a given refrigerant load	No risk of legionella No water consumption No pumping No spray drift Appropriate in humid environments	Higher head pressures lead to lower COP
Water cooled	Circulating pump plus cooling tower components	More efficient Lower condensing pressures (higher COP) Higher summer capacity	Water pumping and maintenance Water consumption Higher maintenance costs Legislative compliance on legionella and other bacteria
Evaporative	Fan and pump power	Most effective in dry environments Highest efficiency due to lowest head pressure	Water consumption Water pumping and maintenance Legislative compliance on legionella and other bacteria More refrigerant required

Air-cooled condensers are generally used for smaller systems.<sup>8</sup> Water and evaporative cooled condensers have the advantage of operating at lower condensing temperatures, improving the efficiency of the refrigeration cycle. The power consumption and water use associated with operation should be taken into account during the selection process.

### **Expansion valves**

Expansion valve performance is vital to the running of a refrigeration system overall. They primarily allow the refrigerant to change state from a hot liquid to a cold liquid at a lower pressure. Different types of expansion valves include:

- orifice plates
- thermostatic, electronic or balanced port expansion valves
- float valves
- hand expansion valve and level switch.

Expansion valves have a very significant role to play in the overall energy efficiency of a refrigeration system – for example, 20% savings have been demonstrated from the use of electronic valves.<sup>16</sup>

### **Motors and drives**

Motors and drives for many components often come as part of an overall package. It is important to look into the efficiency of drives in order to maximise energy savings. Many good energy-efficient motors are available, and variable-speed drives 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.

### **Controls**

To maintain correct operating conditions and optimise 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. Control of compressors, evaporators and condensers should be done in a way that maximises overall efficiency. Control switches respond to physical changes such as pressure, temperature, liquid level and flow velocity. Pressure and temperature controls utilise mechanical adjustments of elements such as diaphragms or discs to instigate the required adjustment. Level-responsive controls use floats, balance tubes or electronic probes for detection. Valves are used to start, stop and regulate the flow of refrigerant to meet the required pressure differentials, temperature and fluid-flow.

### **Secondary distribution system for cooling (coolant, pumps, pipes, valves, controls)**

Secondary or 'indirect' 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. Balancing valves or orifices in each of the multiple feed lines help control and distribute the coolant.

### **Transfer fluids (coolants)**

Transfer fluids, also known as secondary refrigerants, distribute the cooling energy created by the primary refrigerant around a processing plant within the secondary distribution system. Heat transfer fluids include brines, coolants, glycol, calcium chloride, potassium formate, propylene glycol, ethylene glycol, low-temperature fluids, cryogenic fluids, chilling fluids and many other heat transfer fluids. Commonly, a coolant mix of water with 20% glycol and corrosion inhibitors or brine (using salt) is used. A relatively new concept is that of an ice-slurry, which has very high energy-carrying capacity (MJ/kg). Carbon dioxide, which has lower overall environmental impact than many other refrigerants, is a natural refrigerant that can be used in both primary and secondary cooling loops.

## Appendix B

### Life cycle assessment

The increased awareness of the importance of environmental protection, and the possible impacts associated with products, both manufactured and consumed, has increased interest in the development of methods to better understand and address these impacts. One of the techniques being developed for this purpose is life cycle assessment (LCA). LCA 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 nongovernment 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).

There are four phases in an LCA study:

- 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) is the second phase of LCA. It is an inventory of input/output data 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) is the third phase of the LCA. The purpose of LCIA is to provide additional information to help assess a product system's LCI results so as to better understand their environmental significance.<sup>17</sup>
- The interpretation phase – the final phase of an LCA. The findings from the inventory analysis and the impact assessment are combined together, 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.<sup>18</sup>

## Appendix C

### General maintenance checklist

Logging the refrigeration system performance will help identify changes. Obtain the maintenance schedule to ensure the following is being undertaken:

#### Regularly:

- Check the temperatures of cold stores.
- Check evaporator and condenser coils for dirt or debris and clean them if required. Also, check for missing or plugged nozzles.
- 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. Contaminated refrigerant should be purged and automatic purging controls are now readily available.
- 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 air flow of evaporators.
- Ensure that fans, motors and belts have sufficient air circulation.
- Check for plugged line filters.
- Check evaporators are defrosting and 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. Check usage procedures.

#### Monthly:

- Check compressor motor temperature and ensure it is operating as recommended by the manufacturer.
- Check and treat cooling water entering the system. Reduce scale, corrosion and biological growth, as this ensures heat transfer is efficient.
- Check all oil pump and compressor joints and fittings and all relief valves in the system for leaks.
- Check all insulation of pipes, valves and cooler or freezer areas for condition and appropriate thickness.

#### Annually:

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

## Appendix D

### Glossary

<b>chiller</b>	A generic name for a packaged refrigeration system that often includes a compressor, evaporator heat exchanger, condenser water heat exchanger and control system
<b>compressor</b>	Device that accepts gaseous refrigerant from the evaporator and compresses it to a higher pressure before it is sent to the condenser for heat rejection
<b>condenser</b>	Device for rejecting heat from the refrigeration system into the atmosphere. It can refer to a heat exchanger on the side of a packaged chiller, or an evaporative-style unit that incorporates a fan and pumped water system, where hot refrigerant gas becomes a hot liquid
<b>coolant</b>	Secondary refrigerant used to transfer cooling energy created in the refrigeration system around a wider area (for example, a process plant)
<b>cooling duty</b>	The amount of useful cooling work being carried out by a refrigeration system
<b>cooling tower</b>	A structure that provides cooling through the evaporation of water as it passes across a surface, with ambient airflow supplied by a fan
<b>coefficient of performance (COP)</b>	A measure of the efficiency of a refrigeration system defined as cooling duty (kW) / input power (kW)
<b>distribution system</b>	A coolant distribution system that distributes the cooling work done by a refrigeration system into another physical area
<b>energy balance</b>	A tool providing useful information on the breakdown of energy use in a facility 'balanced' against a known total energy consumption
<b>enthalpy</b>	Total heat content including sensible and latent heat



<b>evaporator</b>	Heat exchanger where refrigerant fluid is changed from liquid to gaseous state absorbing heat in the process expansion valve
<b>expansion valve</b>	Valve that is used to reduce the pressure in the refrigerant, allowing it to change from hot to cold liquid
<b>head pressure</b>	Pressure of gas exiting a refrigeration compressor
<b>heat recovery</b>	The process of recovering waste heat from refrigeration system for other purposes, such as preheating domestic hot water
<b>mass flow rate</b>	The rate of movement of a given mass of fluid, usually measured in kg per second
<b>pressure-enthalpy diagram</b>	Thermodynamic chart commonly used to represent a refrigeration cycle
<b>refrigerant</b>	Heat exchange fluid that is vaporised and condensed in the refrigeration cycle to achieve cooling
<b>refrigeration/cooling load</b>	The amount of heat that must be rejected from an area to keep a refrigerated area or process within permissible limits
<b>solar gain</b>	Heating of a process or area from exposure to sunlight
<b>specific heat capacity</b>	The amount of heat required to raise a given substance by 1°C
<b>suction pressure</b>	Pressure of refrigerant at the intake end of the compressor
<b>temperature lift</b>	The difference between evaporative and condensing temperatures of a refrigerant
<b>variable-speed drive (VSD)</b>	A control mechanism that allows control and variation in the speed of a pump or other drive system such as a refrigeration compressor

## Appendix E

### Further reading/references

The following articles and websites provide more detailed technical information and exhaustive best practice methods for improving industrial refrigeration efficiency:

#### Further reading

Best Practice Design, Technology and Management, Sustainability Victoria  
[www.sustainability.vic.gov.au/resources/documents/Module5.pdf](http://www.sustainability.vic.gov.au/resources/documents/Module5.pdf)

Carbon Trust Networks Project: Operational Efficiency Improvements for Refrigeration Systems, Guide 3, p4, Carbon Trust, UK  
[www.ior.org.uk/ior\\_/images/pdf/general/REIG5%20Site%20Guidance%20Topics%20-%20Final%20Jul-07.pdf](http://www.ior.org.uk/ior_/images/pdf/general/REIG5%20Site%20Guidance%20Topics%20-%20Final%20Jul-07.pdf)

Commercial Refrigeration, Energy Smart  
[http://www.sedo.energy.wa.gov.au/uploads/comm\\_refrig\\_28.pdf](http://www.sedo.energy.wa.gov.au/uploads/comm_refrig_28.pdf)

Energy Audit Tool – Chillers Greenhouse Challenge, pp5&9  
[www.climatechange.gov.au/challenge/publications/pubs/energyaudit-vol3.pdf](http://www.climatechange.gov.au/challenge/publications/pubs/energyaudit-vol3.pdf)

Energy management control system for refrigeration plant at Nestlé Ice Cream plant, Mulgrave, Module 5, Sustainability Victoria  
[www.seav.vic.gov.au/ftp/advice/business/case\\_studies/NestleEnergyMgeCase0\\_a.pdf](http://www.seav.vic.gov.au/ftp/advice/business/case_studies/NestleEnergyMgeCase0_a.pdf)

Good Practice Guide 280, Energy Efficient Refrigeration Technology – the fundamentals  
[www.rit.edu/~jdweme/emem416/Fundamentals%20of%20Refrigeration%20Technology.pdf](http://www.rit.edu/~jdweme/emem416/Fundamentals%20of%20Refrigeration%20Technology.pdf)

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