Refrigeration Systems Audit Standard

A standard for the auditing of the energy efficiency of industrial and commercial refrigeration systems

Version 1.0

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0.0 Purpose Statement

This Refrigeration Systems Audit Standard ("Audit Standard") is provided by the Energy Efficiency and Conservation Authority (EECA) for the purpose of providing a quality 'whole-system' auditing methodology for refrigeration systems in common use in the New Zealand industry.

It is expected that, when used by suitably qualified parties (such as an accredited refrigeration auditor), adherence to this Audit Standard will provide the procurer of the audit with confidence that the services received are of high quality.

0.1 Refrigeration Systems Audit Standard

The Audit Standard is designed to guide the collection and analysis of refrigeration system data for the purpose of identifying opportunities for improving the system's energy efficiency and providing relevant technically and commercially sound recommendations.

The Audit Standard is technology-neutral and measurement-method neutral, although the measurement methods used will be important in the context of the scope and measurement accuracy required of an audit.

0.2 Disclaimer

As owner of this Audit Standard, EECA will exercise due care in ensuring that it is maintained as fit for purpose.

However, EECA accepts no responsibility or liability for any direct or consequential loss or damage resulting from, or connected with, the use of this Audit Standard by any party.

Further, this Audit Standard does not seek to represent the obligations of any parties entering into any agreement for services relating to a refrigeration system audit.

0.3 Further information

EECA has commissioned the Energy Management Association of New Zealand (EMANZ) to maintain this Audit Standard, in conjunction with relevant industry stakeholders.

If you have questions in relation to this Audit Standard, you may email info@emanz.org.nz, including the reference "Refrigeration Audit Standard" in the subject line. You may request to be notified when a new version is created.

The current version of the Audit Standard and other relevant information is available by visiting www.emanz.org.nz.

1.0 Overview of the Refrigeration Systems Audit Standard

Refrigeration systems are used extensively to provide essential cooling for various industrial and commercial processes. Such systems include cold rooms, cold stores, freezers, chillers, blast freezers, blast chillers, walk-in coolers and process liquid cooling.

This Audit Standard provides an approach to refrigeration system auditing and analysis. The objectives of the Audit Standard are to:

a) Provide the framework for the systematic collection of data relevant to the efficient operation of refrigeration systems.

b) Enable the refrigeration systems auditor to analyse the performance of the refrigeration system, identify potential energy (electricity) savings and provide sound recommendations for implementation of energy efficiency initiatives.

In addition, Appendices 7 and 8 include recommended report outlines for the purpose of assisting concise, consistent and complete presentation of the analysis, findings and recommendations arising from a refrigeration system audit.

1.1 Scope of the Audit Standard

The scope of the Audit Standard includes industrial and commercial refrigeration systems, based on the vapour compression cycle to provide cooling for various applications. The Audit Standard covers a range of refrigeration system sizes, from walk-in refrigerated spaces to large cold stores. The Audit Standard deals with refrigerated spaces from -45°C to +15°C and includes liquid and process chilling. The Audit Standard excludes air conditioning other than water chilling, very low temperature (less than -45°C) cascade systems, and absorption systems.

Figure 1 shows a simple vapour compression cycle (with direct expansion), which is the basic principle on which most commercial and industrial refrigeration systems are based.

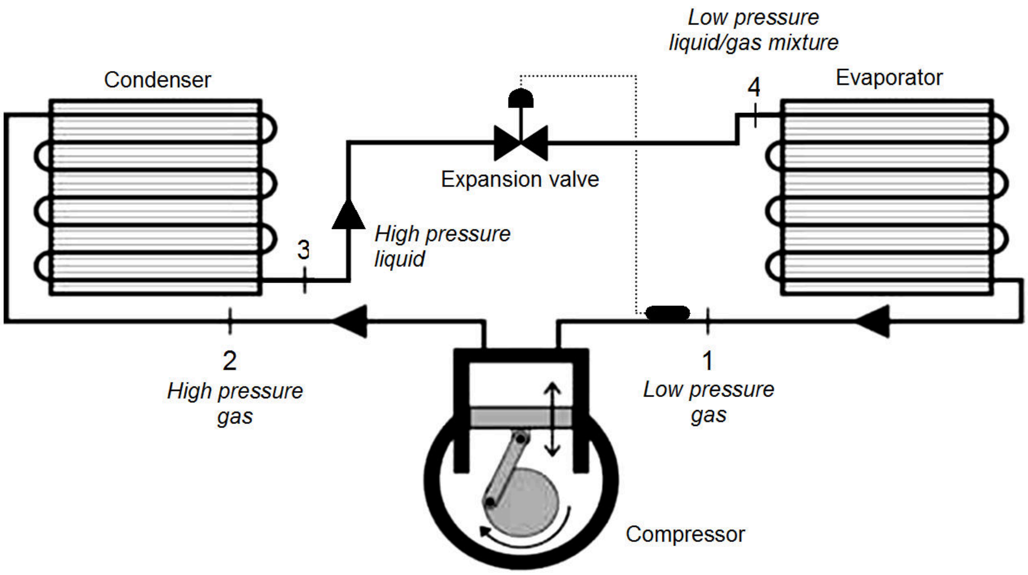


Figure 1: Simple Vapour Compression Cycle with Direct Expansion

Assessing the overall effectiveness and efficiency of a refrigeration system amounts to *minimising the amount of refrigeration required*, and *performing the refrigeration most efficiently*, resulting in the lowest refrigeration cost per unit of end product.

The boundary of the system concerned extends from the energy input into the refrigeration system to the point where the business purpose[1] of producing the refrigeration is achieved.

The system boundary is therefore defined by the points beyond which any change to the system no longer has any effect on the business purpose that the system is serving. The boundary encompasses the whole refrigeration system and includes the building envelope of any refrigerated spaces which are cooled by the system.

Figure 2 shows components within a typical refrigeration system boundary, in this case a large scale two-stage gravity and pump circulation refrigeration system.

[1] An example of a 'business purpose' is cooling required for a necessary process within an industrial system

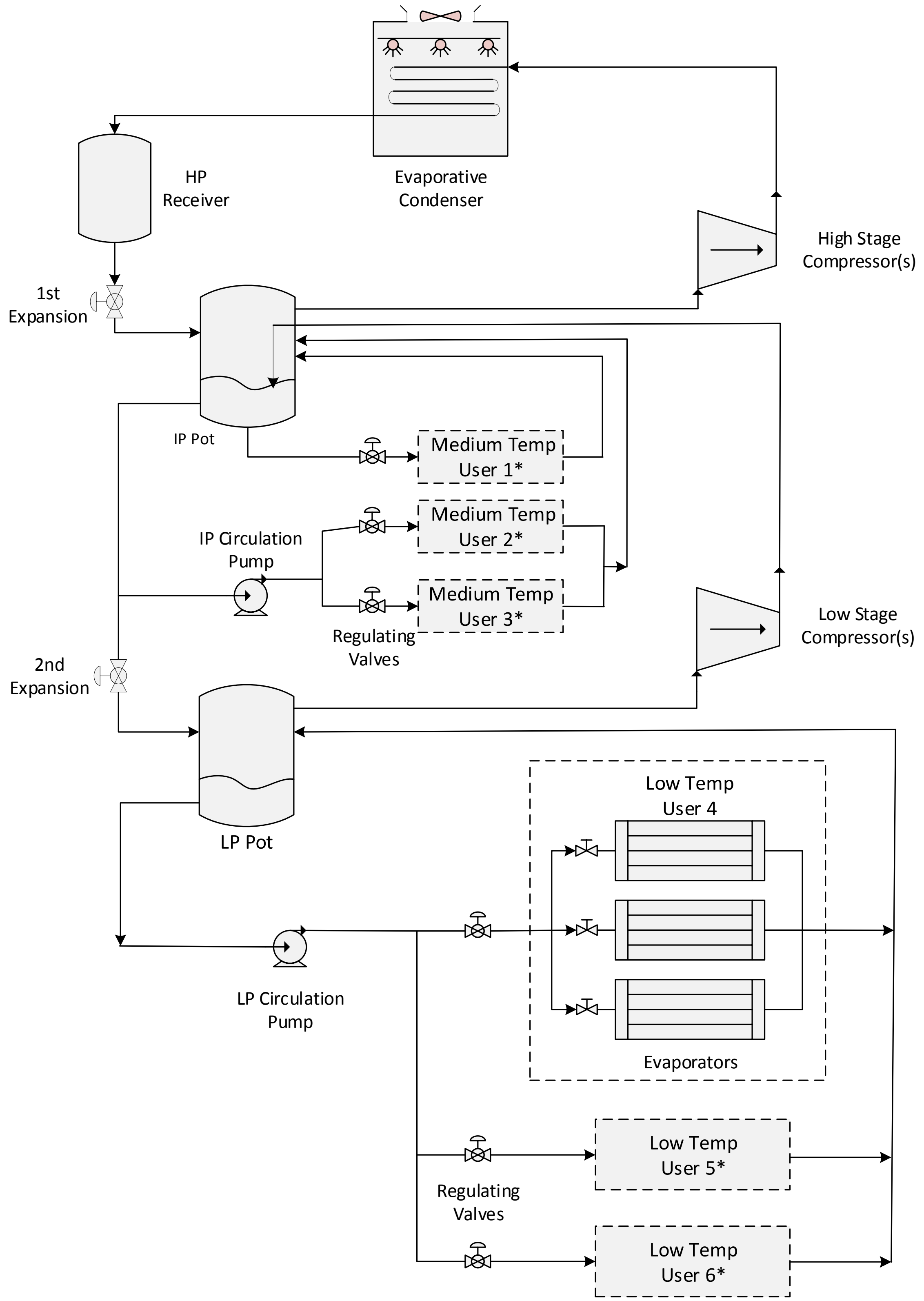


Figure 2: Refrigeration System Boundary – Large Scale Two-stage Gravity (Flooded) and Pump Circulation Refrigeration System

* Users 1, 2, 3, 5 and 6 can include one or multiple evaporator with shut-off and balancing valves, such as those shown for User 4. Medium temperature User 1 is gravity fed; all other users are pumped.

A refrigeration schematic for a standard parallel rack system typically used in supermarkets is shown in Figure 3. A number of supermarkets are now installing cascade CO_2 systems.

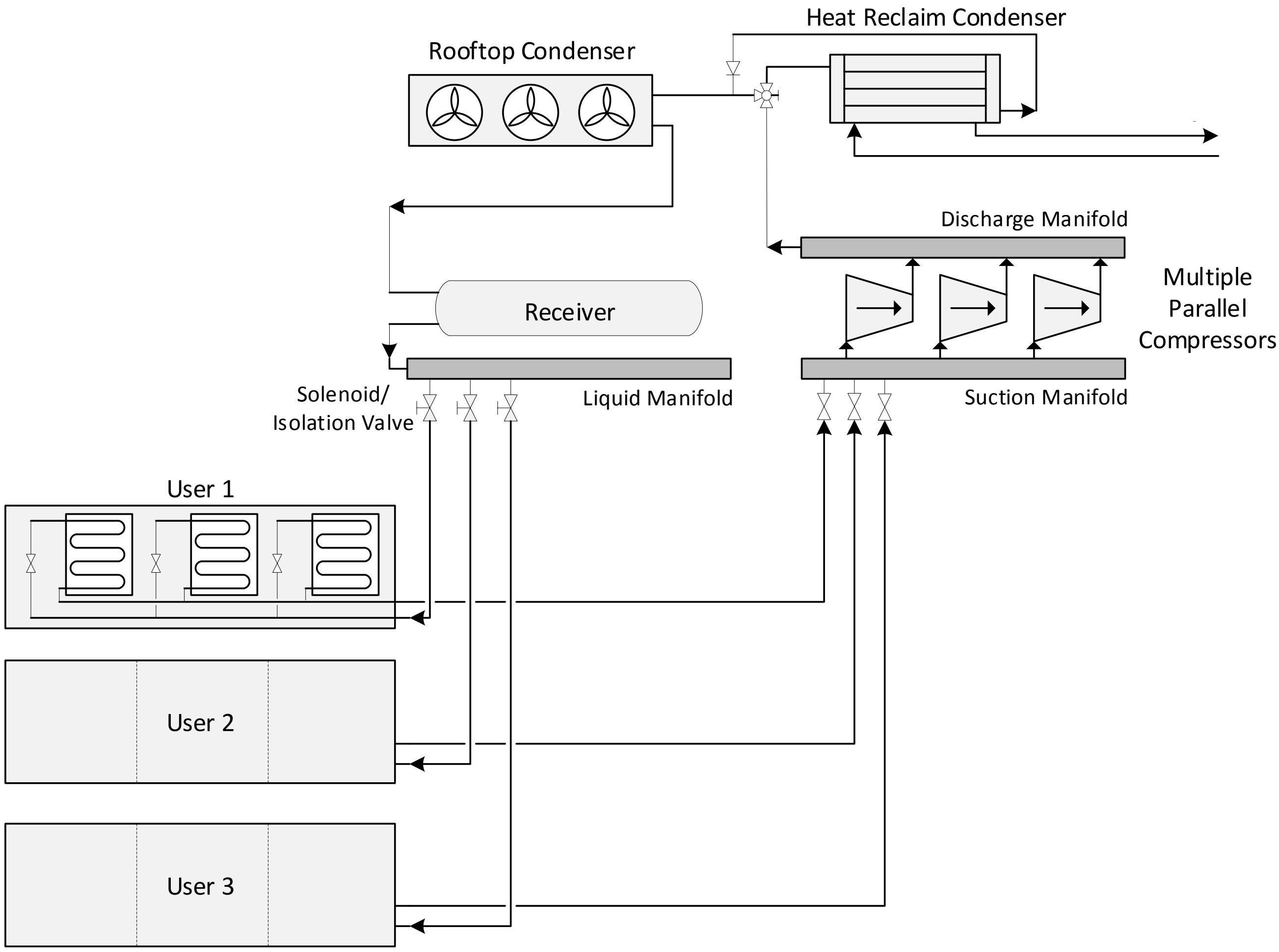


Figure 3: Typical Standard Parallel Rack System found in supermarkets

1.2 Accuracy and Measurement

This Audit Standard includes guidance on the expectations of audits conducted according to two generalised levels of accuracy requirements — a 'base level' and an 'investment level'. These levels are representative of two ends of an accuracy requirement continuum. Where on that continuum the audit fits is a matter for agreement between the auditor and the client, and will be determined by the client's purpose in commissioning the audit.

This Audit Standard is measurement-technology neutral, but indicates some preferences with regard to the measurement methods and associated equipment appropriate for the accuracies required. The implications of measurement accuracy on audit accuracy are described in Appendix 5.

Base level audits are primarily intended to identify areas of inefficiency and opportunity in the system. A typical base level audit generally does not include extensive use of flow, temperature, pressure and power measurement equipment.

A base level audit may be the appropriate level to use to define the scope and measurement requirements of a subsequent investment level audit of the same system.

The accuracy required for the level of audit to be undertaken is presented in Table 1. A base level audit allows a margin of error of up to ± 50% for the whole system, due to the uncertainties surrounding parts of the refrigeration system which are unable to be investigated in detail.

	Base level audit [2]	Investment level audit [3]
Cost	± 50% error	± 10% error
Energy Savings	± 50% error	± 20% error

Table 1: Allowable Margins of Error for base level and investment level audits

[2] A base level audit is equivalent to an AS/NZS 3598:2000 Level 1 audit, in which a site walk-through is conducted, followed by brief analysis of opportunities identified

[3] An investment level audit is equivalent to an AS/NZS 3598:2000 Level 3 audit, in which a detailed site visit is conducted, followed by detailed analysis of opportunities identified

2.0 Planning the Audit

2.1 Audit Objectives and Scope

Each audit should be scoped and designed according to the client's requirements. Consulting with the client to identify and record the client's objectives is a critical prelude to defining the scope of the audit and the associated measurement requirements.

An audit for a client who is seeking only to understand where the refrigeration system's efficiency opportunities exist in a factory may have lesser scope and measurement requirements than an audit that is required for a client who needs the audit findings as crucial inputs into a potential efficiency upgrade investment.

The measurement accuracy requirements should be discussed and agreed at the outset with the client, and will inform the decisions regarding methodology and equipment used for the audit.

Agreement on audit objectives and scope should include agreement on the content and structure of the audit report that will be subsequently presented to and discussed with the client.

AS/NZS 3598:2000 may be used to guide expectations for both the client and the audit team in terms of what is expected from the audit and required of the audit team.

2.2 Business Context

The business context of the refrigeration system(s) to be audited, or what is required of the system(s) in the wider business operation, needs to be established in order to define the measurement requirements for the audit and any post-implementation phase.

The principal purpose of the audit is to provide information that will identify ways to improve the efficiency of the refrigeration system. The demand on the system and the business needs which are driving that demand must be understood from the outset[4]. This is important for meaningful monitoring of the refrigeration system's energy performance, after the implementation of any changes.

When planning the audit, the relationship between the energy input to the refrigeration system and the business driver of the refrigeration system should be identified. The driver may be measured through one of a range of factors, such as hours of operation, production input (e.g. daily kg of material), production output (e.g. daily kg of product), product turnover and square meters or cubic meters of refrigerated storage space. Depending on the particular business, multiple performance metrics may apply. These should be discussed with the client to understand which metrics are the most meaningful for them.

2.3 Audit Timing

For an investment level audit, the timing of the audit needs to allow the auditor to understand any daily, weekly and seasonal variations of the system. This will then allow the fraction of the year, week or day at which the load is a certain amount to be quantified. For example, if a site requires process cooling at harvest time for a brief period of the year and then changes to a cold storage mode for the remainder of the year, two site visits may be required to capture information for each of these periods. Many sites experience weekly and/or daily cycles in operations (e.g. low activity and lower need for refrigeration at weekends and overnight due to little/no production). The timing of the audit affects the measurements taken at the site, which will affect the conclusions drawn from the findings and hence influence the recommendations made to the client.

A best case scenario is one where a SCADA system monitors the refrigeration system continuously, providing annual hourly or fractional hourly data (eg. gaining data for a trim compressor to justify the installation of a variable speed drive (VSD)).

2.4 Resources and Responsibilities

2.4.1 Resource Requirements

The audit scope and accuracy requirement agreed with the client will determine the people and other resources required to perform the audit. The audit quotation presented to the client (which will form the basis of the service agreement subsequently established with the client) needs to include an assessment of the resource requirements.

[4] For example, the demand on a refrigeration system may be the blast freezing of packaged meat within a meat processing plant. The business context is processing meat, not merely the operation of the blast freezers.

Irrespective of whether a base level or investment level audit is required, a fully competent refrigeration system auditor shall be engaged for the audit.

An equally-competent refrigeration system auditor should be available to provide peer review of critical parts of the analysis and findings of investment level audits.

2.4.2 Audit Functions and Responsibilities

The audit requires 'managing' and 'expediting' functions to be performed and, where an audit team is involved, it requires an allocation of the various audit responsibilities. The functions included within each of those areas are as follows:

Audit Managing: to ensure that the audit is managed to deliver a quality output, on schedule. Managing includes ensuring:

a. The audit is appropriately scoped and priced

b. The audit resource requirements are accurately identified

c. A service agreement is established with the client

d. Audit tasks are allocated to appropriately skilled individuals

e. A clear work schedule exists for the onsite activities and delivery of the final audit report

f. The client delivers on its responsibilities under the service agreement

g. The client provides any past audits that have been conducted

h. If the refrigeration system is serviced by an external party then the client will need to make that external party available

i. Any third-party contracts are facilitated and managed

j. The client and peer reviews (as required) are completed.

If the refrigeration system is serviced by an external party then the client will need to make that external party available.

Audit Expediting: to ensure the required data is collected according to the audit scope and objectives, in a manner that is consistent with the requirement of this Audit Standard. Expediting includes the following:

a. Liaising with the site operations, maintenance and engineering staff to ensure site procedures are recognised in the logistics of the audit.

b. Collecting and analysing the audit data.

c. Obtaining peer review of findings (depending on audit scope and objectives).

d. Drafting and finalising the audit findings and recommendations.

It is expected that these functions will be performed by a refrigeration system auditor who has demonstrated to have appropriate experience and is certified or accredited by an independent certification body or reputable professional association, such as EMANZ.

2.4.3 Communications

An initial meeting between the audit manager and relevant site management should clarify the audit objectives and scope.

A second meeting involving the auditor, site management and operations staff, and external providers should be held to complete the following:

a. Review any preliminary (pre-audit) information that has been collected.

b. Assist refinement of the measurements, tools and methods required for the audit to ensure client expectations will be met.

c. Ensure that there is an understanding of what resources are required onsite, as well as any required employee involvement.

2.5 Audit Costing

Costing of the refrigeration system audit is an important part of the audit planning process.

For an investment level audit, the cost will depend on the size of the site, the number of refrigeration systems and system boundaries that have been defined in the scope, the level and duration of power, temperature and pressure measurements required, and any third-party contractors required to undertake measurements. It might also need to include recognition of post-audit performance monitoring that may be required by the client.

For a base level audit, the measurement and reporting requirements will be significantly less — with a flow-on effect on the auditing cost estimate.

The quoted cost to the client should also take into consideration any support available from third parties. For instance, there may be services or funding provided by suppliers/manufacturers of refrigeration systems/components, energy retailers, and potential support from central government or other parties.

2.6 Audit Approach in Summary

Figure 4 outlines the general audit approach that should be followed. It commences with client consultation regarding the objectives and scope of the audit (as covered in 2.1 above).

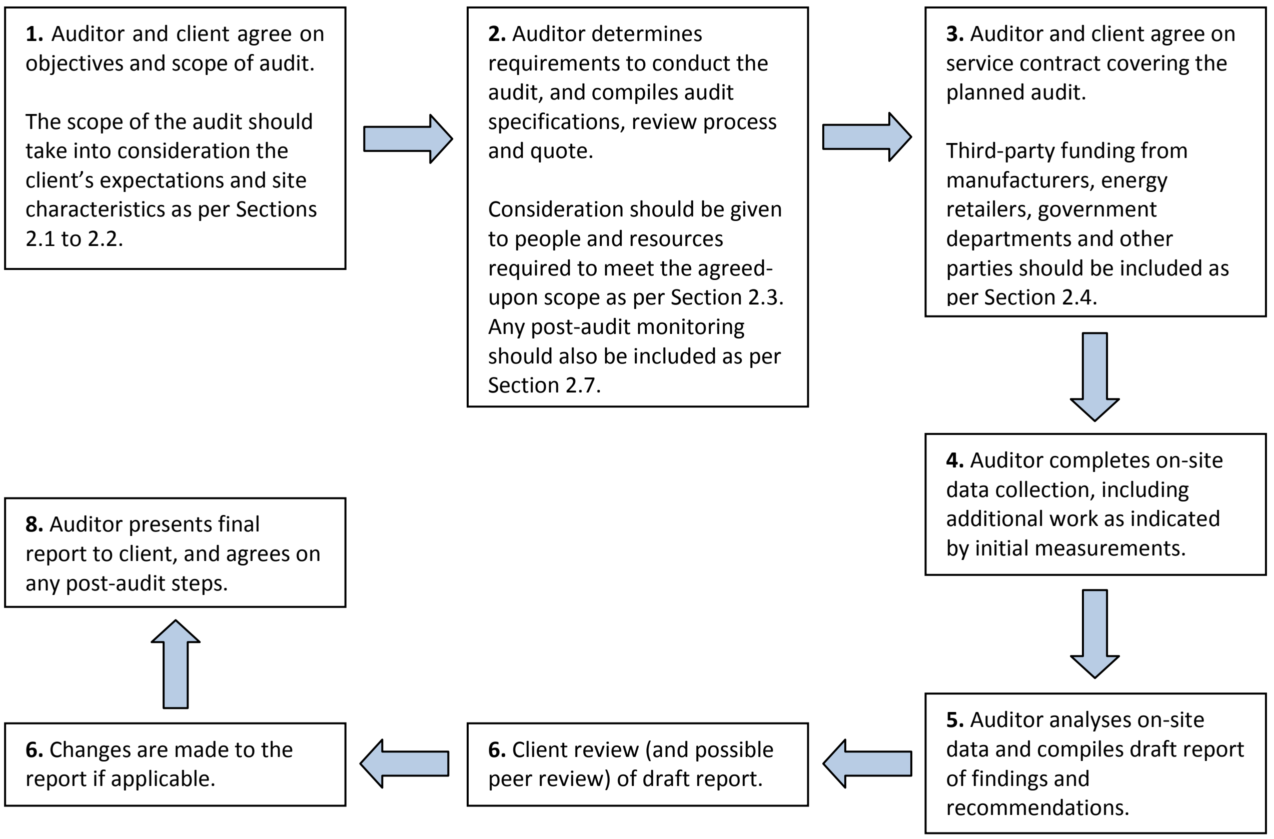


Figure 4: Flow Diagram of Audit Approach

2.7 Post-implementation Monitoring

An audit will generally be followed by the implementation of recommended corrective actions.

Post-implementation monitoring of electricity usage relative to the refrigeration system requirements or business driver is generally important to the client to enable the value of post-audit design or operational changes to be measured on an ongoing basis.

The nature of the post-implementation monitoring should be established as part of the audit planning, as it is likely to influence some aspects of the audit design and location of temporary or permanent measurement equipment. The key driver of refrigeration system electricity input should govern the nature of the monitoring, whether that driver is production output, another output or merely hours of operation.

In the event that the client requests a post-implementation verification audit, the scope and nature of that audit should be agreed between the client and auditor prior to the commencement of the original audit process.

3.0 On-site Measurements and Data Collection

This section details the measurement requirements for a refrigeration system audit conducted to investment level accuracy. It also provides some guidance on what may be sufficient when auditing to the (lower) base level accuracy.

In the first part, the measurement methods are outlined, followed by the measurement requirements for the site and systems being audited.

As discussed in Section 2.3, the audit period needs to take into account and align with any daily, weekly and seasonal variations of the refrigeration system.

Measuring the refrigerant flow within a refrigeration system is practically challenging and is not required as part of this Audit Standard.

3.1 Historic Energy Use

The historic energy use of the site needs to be collected either during or prior to the site visits for the systems that are under investigation. This information should be obtained for the previous 12 months, in order to identify the overall consumption and costs at the site.

3.1.1 Electricity Usage

The type of information on electricity usage typically depends on the size of the site. For small sites monthly invoices should be obtained. For large sites it is preferable to access half-hourly electricity consumption data (available online). The data required needs to be adequate to match the accuracy of the desired analysis including any daily, weekly and/or seasonal variations.

3.1.2 Fuel Usage

If heat recovery opportunities are identified during the audit process and a non-electric boiler is used, then the cost and consumption of heating fuels will need to be determined. Heat recovery from the refrigeration system can reduce heating fuel demand and therefore reduce heating costs.

Only the fuel consumption of the particular heating system whose load could be reduced by implementing heat recovery opportunities needs to be considered. Fuel usage can be determined from existing monitoring which may be undertaken by staff at the site or from delivery invoices.

If a boiler is used at the site, flue gas test reports will need to be obtained to determine its overall efficiency. Once the efficiency is known, the cost per kWh of heating can be calculated.

3.2 Cost Estimations

Cost estimations of electricity, fuel and recommended implementation are an essential part of any audit since they directly influence the economical viability of energy management opportunities.

3.2.1 Electricity Cost Estimation

Wherever the audit findings are likely to be used in any investment analysis, the electricity costs used in valuing the electricity consumption of the refrigeration system should be based on future contract or forecast prices and adjusted for any other relevant variable pricing factors, as agreed with the client.

Annual average prices can generally be used unless there are considerable seasonal variances in production (refrigeration system demand) patterns. Any daily, weekly and seasonal electricity price variations should be recognised in any calculation of production-weighted annual average prices.

The effects of any demand and/or capacity charges need to be accounted for. Where differences in electricity use are being valued, the valuation needs to consider that some elements of the delivered electricity price may be independent of the consumption level. Any fully fixed elements of the electricity price need to be removed from the cost used to value a consumption difference.

For the purposes of a base level audit, if the client does not have a standard electricity cost figure for project analysis purposes, it is generally acceptable to use the most recent 12 months' gross average electricity cost (total cost divided by total energy consumed) for the valuing of electricity use.

If relevant, the effect of power factor on delivered electricity costs to the refrigeration system should be recognised. On most electricity distribution networks, a premium is chargeable if a power factor of less than 0.95 is measureable at the site-entry metering point.

The absence of power factor correction equipment on the site would normally result in a recommendation to the client to investigate the economics of correcting that situation.

3.2.2 Fuel Cost Estimation

As for electricity consumption, wherever the audit findings are likely to be used in any investment analysis undertaken by the client, the costs used in valuing the fuel consumption of the heating system should be based on future contract or forecast prices and adjusted for any other relevant variable pricing factors, as agreed with the client.

Annual average prices can generally be used unless there are considerable seasonal variances in production (heating system consumption) patterns.

Fuel consumption differs from electricity consumption in that combustion efficiency and thermal efficiency must also be taken into account to determine the true fuel cost (or 'effective energy cost'). For example, in the case of a steam boiler system, combustion analysis of the burner may reveal a fuel combustion efficiency of 80% during typical operating conditions and the heat losses from the boiler are 4% of its rated output. For a fuel cost of $0.04/kWh, the effective energy cost for any user of the steam produced is therefore $0.052/kWh of useful heat, ie. $0.04/[0.80 x (1 – 0.04)] = 0.052.

For the purposes of a base level audit, if the client does not have a standard fuel cost figure for project analysis purposes, it is generally acceptable to use the most recent 12 months' gross average fuel cost (total cost divided by total energy consumed) for the valuing of fuel use, and typical combustion and thermal efficiencies can be assumed.

3.2.3 Works Cost Estimation

Particularly where the audit is undertaken for investment proposal purposes, the findings will include recommendations for works to be performed to exploit efficiency opportunities.

With guidance from the client with regard to whom to consult with, it is expected that compiling budget estimates for such recommendations will require consultation with a range of equipment suppliers or maintenance engineering companies. The level of accuracy of the cost estimates should meet the client's requirements. For investment proposal purposes, the accuracy expectation will typically be in the order of ±10%.

3.3 Measurement Equipment and Methods

There are a range of measurement methods available to auditors. Judgement is required to select the appropriate measurement technology, depending on the particular refrigeration system and the technologies being used.

3.3.1 Accuracy of Measurement Equipment

All equipment used by the auditor to carry out the audit shall at all times be maintained and calibrated to the relevant standards and manufacturers' specifications. For example, the SCADA system sensors will need to have been calibrated.

3.3.2 Pressure Measurements

Pressure can usually be measured with a suitable gauge in parts of the system where appropriate service fittings are already installed. If not, a refrigeration technician would be required to provide the pressure measurements. The auditor's pressure loggers may be used if pressure sensors can be practically installed, although this is not mandatory. Most large refrigeration systems have in-built pressure measurement systems and may also have a SCADA system. The SCADA would be able to provide pressure measurements over time.

Pressure measurements should focus on compressor suction and discharge and at relevant points in the suction and discharge pipe network, since these pressures and pressure drops are most critical to the performance and energy consumption of the system.

For a base level audit, it is recommended that values are noted if there are gauges already in the refrigeration network.

A digital manometer should be used to measure the air pressure difference between refrigerated spaces and adjacent spaces, as part of the refrigeration load measurements. High air pressure differentials indicate potential for high levels of air infiltration.

3.3.3 Temperature Measurements

Knowledge of the liquid and vapour temperatures are crucial to understand a refrigeration system's performance. Temperature measurements vary depending on the part of the refrigeration system being measured, whether the substance is gaseous, gas and liquid, liquid or solid, as well as the accuracy of the measurement required. Temperature measurements can be categorised into three groups based on the state of the substance being measured:

- Gas Temperature — a thermocouple or resistance temperature detector (RTD) is generally sufficient. In addition, either a wet bulb thermometer or relative humidity sensor is required for air measurements in refrigerated spaces and ambient air.
- Liquid Temperature — for low-pressure situations an RTD is sufficient, while at higher pressures the thermometers must be in thermowells (often already installed at various locations throughout a refrigeration system).
- Solid Temperature — if the solid surface is accessible and uninsulated, a thermocouple or RTD is recommended.

  However, for less-accessible surfaces thermal imaging cameras and/or optical pyrometers are very useful. Thermal imaging cameras are particularly useful for insulation surveys of the piping network of refrigeration systems and insulated building structures. It is important to note that the emissivity of solid surfaces must be known, as this parameter is used by thermal imaging software to determine the temperature of a material's surface. Particular caution must be taken when measuring the temperature of surfaces with low emissivity, such as stainless steel, as this may lead to large measurement errors.

  Temperature probes can be used for taking internal product temperature measurements, if appropriate.

Many refrigeration systems have control systems with temperature measurement capability and may also have a SCADA system. The SCADA would be able to provide temperature measurements over time.

In all cases of temperature measurement, the most accurate measurement will be taken directly from gas or liquid flows. If this is not possible, the surface temperature of piping can be used, and in this case purpose-manufactured surface temperature probes need to be used.

3.3.4 Flow Measurements

Using flow measurement equipment to determine the flows of primary refrigerants through system components within a refrigeration system can be both impractical and inaccurate. It is not always possible to gain access to pipe work in order to install the equipment and the flow measurements obtained can have a significant error associated with the measurements. Both turbine and ultrasonic flow meters have been successfully used for refrigerant flows in high pressure liquid lines. The measurement point needs to be located sufficiently far downstream of a pipe fitting to gain a representative reading. Refrigerant in the cycle can be liquid, vapour or a two-phase mixture depending where the measurement point in the cycle is. Due to the different phases present, the flow measurements can be highly inaccurate. Flow measurement for secondary refrigerants such as water, brine or glycols is more straightforward using standard liquid flow meters.

Knowledge of air flows is important to understand the heat transfer occurring in specific parts of the refrigeration system. It is typically important to determine the air flow off the evaporator coils, condenser fans and any air infiltration through doorways or seals. Air velocities can be measured with vane anemometers and hot wire anemometers. Larger vane anemometers with a diameter of 100 mm are typically more accurate than smaller anemometers. Air flow measurements made with anemometers need to systematically traverse across the area of interest to determine the velocity profile and hence calculate the average flow rate.

Measurement of defrost melt water can help assess defrost efficiency. A useful measuring technique is a bucket or drum with scale markings to capture water which is melted during defrost cycles. The flow of water should be measured over time.

As mentioned in Section 3.0, although measuring the flow of refrigerant within the refrigeration system is not a requirement, the performance of the compressor(s) should be identified as part of the audit. This can be determined using manufacturer's data, rather than refrigerant flow measurements.

3.3.5 Electricity Usage Measurements

For investment level audits, the input power to each piece of electrical equipment being investigated should be measured at a point that excludes other extraneous load. This can be challenging, since in most cases in industry there are multiple loads being supplied by each meter and it is not always clear which loads are connected to which meters. If the loads cannot be separated, then the electricity usage measurements may have to be aggregated.

Ideally, for each major piece of equipment, a three-phase electricity meter (with data-logging capability) should be used to directly record kilowatt (kW) and kilowatt hour (kWh) usage. Preferably, measurements of current and voltage allowing the calculation of apparent power (kilovolt-ampere – kVA), should not be used, since the power factors for each piece of equipment will not be the same and can fluctuate depending on the motor loading. If only current measurement is available then the typical power factor of the equipment needs to be estimated so that kW use can be calculated from kVA readings.

The frequency at which the electricity data should be logged will depend on the operating characteristics of the equipment being monitored. If the refrigeration system has variable demand requirements or for loads that change often, such as changes in product flow rate or frequency of door openings, it is recommended that the power readings are logged at intervals no greater than 1 minute. For applications such as logging a compressor for a cold store, this logging interval could be increased to 15 minutes if the cooling load is relatively stable. The auditor needs to judge the maximum interval appropriate for the given application.

If the lighting types, wattage and hours of operation are known, then the heat load from lighting in refrigerated spaces can be calculated, rather than measured. This reduces the amount of electricity metering which has to be performed.

If the electricity line charges are based on kilovolt-ampere (kVA) measurements and the site does not have power factor correction upstream of the refrigeration compressors, kVA demand should be either directly measured or otherwise assessed.

Measurements should be taken for a period of time sufficient to capture the 7-day operational pattern of the refrigeration system. In addition, in order to put the weekly profile into an annual or seasonal usage context, it is necessary to obtain an annual profile of production and/or electricity usage. Investment level accuracy of the annual usage estimate requires consideration of both the weekly and annual profile data.

For base level audits, the table provided in Appendix 3 identifies the data required to estimate a refrigeration system's annual electricity usage without the use of extensive electrical data logging.

3.4 Refrigeration System Measurements

3.4.1 Data Collection

Appendix 1 contains a form outlining the basic site information that should be recorded for the audit, irrespective of the accuracy level of the audit concerned.

Appendix 2 contains system data collection forms for an investment level audit of a refrigeration system. There are several sources of data that can be utilised to collect this information, such as plant personnel, equipment nameplates, equipment operating manuals, system drawings and supplier catalogues. It is important to note that documentation is often out of date or redundant due to system changes, in which case onsite staff are usually the most valuable sources of information.

A less detailed data collection form that is suitable for a base level audit is included in Appendix 3.

A checklist of the energy savings opportunities, which should be investigated at the site, is included in Appendix 4 and should be used regardless of the audit level. Some of the more important items within Appendix 4 are discussed in more detail in Sections 4.3 to 4.7.

3.4.2 Business Requirements of the System

Understanding the requirements that the business have for the refrigeration system being audited is a prerequisite to identifying areas of inefficiency. It is useful to commence the audit with quantification of that requirement, which necessitates collection of the following information:

- The functional requirements (e.g. air temperature, production volume, cooling time) of the system relative to the main business driver (e.g. production).
- Any changes to the system design since installation and the reasons why.

A refrigeration system schematic is important to provide a clear picture of the interrelationships between the system components and how the requirements may be delivered. If there are multiple systems at a site then the business requirements need to be identified for each system. The business should specify which metrics are important.

3.4.3 Operating Characteristics

An understanding of the actual (as opposed to the required or design) operating characteristics requires data collection across the demand, network and supply components of the system, and quantifying the relationship between electricity use and the relevant business driver of system demand. Run hours are typically the most important factor for small systems, whereas for large systems the percentage of full load at which the system is operating is typically the most important factor.

Appendix 2 contains forms that identify the data required to understand the operating characteristics and are useful for an investment level audit. More detail on the measurements of that data is provided below.

For base level audits, Appendices 3 and 4 provide several forms that identify:

- A minimum level of data needed to estimate a refrigeration system's annual electricity usage.
- A checklist that could be used to assess the key components of the system as they affect system efficiency.

System-run data should be verified by site personnel wherever possible, as the economics of potential efficiency opportunities will depend heavily on that information.

3.4.4 Electricity Usage and Business Driver Relationship

The audit should be able to quantify the Refrigeration System Electricity Intensity (REI), expressed as the total electricity consumed by the refrigeration system per unit of the productive business driver (e.g. kWh per kg of production output). In addition, the audit should determine (and quantify) any relationship between the REI and the different levels of production activity or seasonal effects. As discussed in Section 2.2, multiple metrics can be used to provide the most meaningful set of metrics for a particular business.

As a secondary measure for investment level audits, the baseline electricity usage measurement obtained from the audit should allow quantification of the Coefficient of Performance (COP), expressed as the refrigeration output per unit of electricity consumed (e.g. the kW of heat removed from the refrigerated space per kW of power input to the refrigeration system, including the compressors, refrigerant pumps, condenser fans, evaporator fans, condenser pumps, secondary pumps etc).

The nature of the monitoring should be governed by the key driver of the refrigeration system electricity input (e.g. production input, output or simply the hours of operation).

For practical purposes (particularly for post-implementation monitoring) the REI may be established by metering a small number of key 'reference meters' rather than attempt to measure energy consumption for all consumers in the refrigeration system. Key meters should include the refrigeration compressors.

3.4.5 Demand Measurements

It is important to begin the analysis from the demand side of the refrigeration system, as this is the load that the system has to meet. The demand dictates refrigerant flow, pressure and temperature requirements and the capacities of the compressor, evaporator and condenser. These requirements then dictate the energy consumption of the equipment within the refrigeration system itself.

Measurements relating to the refrigeration demand loads for each refrigeration user are tabulated in Appendix 2.

For small refrigeration systems, a significant portion of the cooling demand is typically due to transmission through the insulation, open and unprotected doors, long defrost cycles, lighting and thermal loads from evaporator fans.

Pressurisation of spaces adjacent to any refrigerated space will influence air infiltration. As a result, relative air pressure measurements between the spaces (such as provided by a manometer) need to be taken to determine air infiltration potential (e.g. between a boning room and the refrigerated rooms).

Evaporator defrost information needs to be measured and collected from the site. This information includes defrost cycle times, activation methods, durations and melt water recovered versus defrost time.

3.4.6 Network Measurements

For each system being audited, record key characteristics of the network delivering and returning the refrigerant, giving consideration to the following:

- Pipework configuration and sizing — note unnecessarily long pipe runs or undersized and/or unsuitable joints and valving.
- Pressure should be measured at locations where significant pressure drops are likely to occur, such as a vertical wet suction riser or tortuous pipework. These measurements are dependent on the pressure test points which are available at the site.
- The level of system maintenance practiced.
- The effects of any alterations made on the refrigeration system network's original design.
- Temperature measurements of pipework and other components to determine heat gains. This is useful for later analysis of potential insulation opportunities.

A table for recording the network measurements is included in Appendix 2. Note that identifying areas of high refrigerant pressure loss and friction loss may require additional software assistance. There are software packages available that may aid in identifying potential network inefficiencies.

If ammonia is used as the refrigerant for a site and if an investment level audit is being undertaken then the ammonia needs to be checked for water content, in addition to the tabulated measurements in Appendix 2. Water in ammonia systems will cause inefficiencies and the build-up of debris. Testing for water is a requirement if frequent air purging occurs in the refrigeration system (e.g. system operates at vacuum pressures) or an opportunity exists for water leaking from the oil cooler and/or the process coolers into the refrigerant. The lowest temperature point in the system should be sampled using a pipette. After the sample is allowed to vapourise, the remaining volume of any water can be checked. Corrective action should be taken if over 2% of water is measured from the sample.

3.4.7 System Measurements

For each system being audited, the key characteristics of the supply side of the refrigeration system need to be recorded. These measurements relate to the refrigeration compressors, oil coolers, evaporators and condensers. Appendix 2 contains a data sheet that should be completed during the site visit for an investment level audit.

To determine the efficiency of the compressor, the kW and kVA load on the machine needs to be recorded with an energy meter when the compressor is fully loaded. This may require the sequencing of the machines being adjusted during the measurement period.

4.0 Data Analysis

For a base level refrigeration system audit, observations and measurements are relatively low in detail, and analysis consequently relies on significant assumptions. In many cases, it will be impossible to make any further conclusions about the operation of the system without equipment to take more in-depth measurements.

For an investment level refrigeration system audit, observations and measurements must be in much greater detail. This minimises assumptions that must be made for subsequent analysis. In some cases it still may be impossible to draw further conclusions about the operation of the system if the information such as relevant temperature measurements, electrical loggings and pressure measurements cannot be obtained.

It is important to note that any assessment should focus first on the demand side of the system, before any optimisation of the supply side. Supply-side measures are commonly investigated without first considering potential measures to reduce the demand, which is not ideal.

4.1 Regression Analysis

Regression analysis is a useful tool that can be used to relate the energy consumption of the refrigeration system to independent variables which are thought to influence consumption, such as cooling degree days (the amount of energy required to cool the business) and production throughput. Other site-specific variables may be important and can be included. Regression models can aid in determining if there is a correlation between the independent variables and consumption. This allows insight for both the auditor and the client into how the system operates in different conditions.

4.2 Demand Load Calculations

The starting point for calculations performed after a refrigeration system audit is to determine the heat loads placed on the system. This can be performed once the relevant data has been collected, as discussed in Section 3.4. The following heat loads need to be calculated for each refrigeration end user for each system:

- Product loads
- Air infiltration due to open doors, open display cases or poor door seals
- Heat transfer through the building envelope into the refrigerated space
- Defrost loads
- Evaporator fan loads
- Lighting
- Equipment (e.g. processing equipment in Ready to Eat areas)
- Underfloor heating
- People.

These loads can be represented in a pie-chart, such as the example shown in Figure 5.

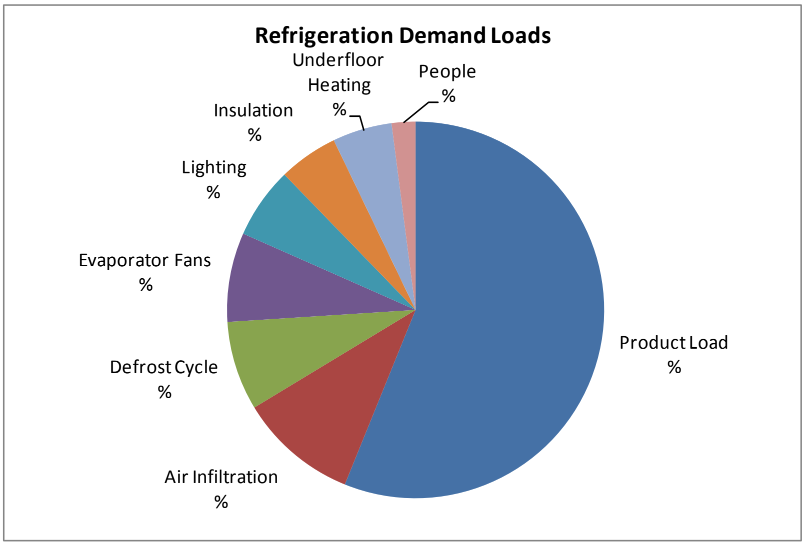


Figure 5: Pie-chart of Refrigeration Demand Loads

Calculation of the heat loads for each user allows the auditor to quantify which energy management opportunities will have the greatest influence on reducing the cooling demand placed on the refrigeration system. The refrigeration demand can then be compared to the capacity of the refrigeration system.

The *2010 ASHRAE Handbook – Refrigeration* (2010)[5] should be consulted for additional information regarding refrigeration load calculations. It is important to assess the variation of these loads with time (daily, weekly and seasonally) and the diversity of the load (for large systems with multiple refrigeration applications).

4.3 Refrigeration System Performance

The data measured and collected at the site should be compared with relevant performance information specified by manufacturers and suppliers, to identify any areas of concern.

The actual measured performance should be checked against manufacturers' data. Any large discrepancies found during the comparisons will then indicate an area that needs closer attention, in order to understand why there is a difference.

Once the cooling loads on each refrigeration end user have been calculated, these can be compared to the cooling being supplied by the evaporators. This should then be compared to the cooling which is being delivered by the compressors and the heat being rejected by the condensers or cooling towers.

Evaporator Load = ∑ Cooling Loads (including losses)

Compressor Load = ∑ Evaporator Loads on that compressor suction

Condenser Load = Evaporator Load + Compressor Energy Consumption (minus motor inefficiencies if open drive) – Oil Cooling (if the oil cooling is not provided by the condensers)

Three types of data are required in order to calculate the evaporator performance: air/fluid flow, temperature differentials and manufacturer's data. Due to typical data uncertainty and variation with time, the differences between estimated heat loads and measured evaporator capacities can be quite large (i.e. it can be difficult to close the energy balance to better than ±20%). The evaporator performance should be determined from the manufacturer's data based on entering air or liquid temperatures, air or liquid flow rate (if variable), and refrigeration pressures and temperatures. If the difference between the manufacturer's data and actual measured performance is greater than 20% then it can be indicative of an evaporator problem.

The operating conditions (suction pressure and temperature, discharge pressure and fractional loading) and manufacturer's data need to be used in order to calculate the compressor refrigerating capacity and energy consumption. The difference between compressor capacity and evaporator loads can be quite large due to uncertainties in measuring evaporator performance. However, differences of greater than 5% between the measured compressor energy use and the manufacturer's data for the same operating conditions can be indicative of a compressor problem.

Three types of data are required in order to calculate the condenser performance: air/fluid flow; temperature differentials; and manufacturer's data. The condenser performance should be determined from manufacturer's data based on entering air or liquid temperatures, air or liquid flow rate (if variable), and refrigeration pressures and temperatures. If the difference between the manufacturers' data and the actual measured performance is greater than 10% then it can be indicative of a condenser problem.

4.4 Demand Analysis and Opportunities

Analysis of cooling demand requires the optimisation of refrigeration use (Appendix 4). Solutions to improve the efficiency of this use include, but are not limited to:

- Manual or automated isolation of refrigeration users when cooling is not required.
- Scheduling the system operation outside electricity network peak charge periods.
- Reducing product heat loads placed on the refrigeration system (e.g. pre-cooling products).
- Improving the insulation of refrigerated spaces to reduce heat transfer (e.g. maintain vapour barriers in good condition).
- Improving door management and protection (e.g. strip curtains).
- Improving door seals.
- Optimising product freezing times (e.g. with reduced fan speed).

[5] *2010 ASHRAE Handbook – Refrigeration.* (2010). Atlanta, GA: American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc.

- Analysing the cooling load to identify if a user can be supplied with a higher suction pressure refrigerant.

Reduction in the use of refrigeration on the demand side ultimately reduces the energy input required from equipment such as compressors, fans and pumps within the refrigeration system.

4.5 Evaporator Analysis and Opportunities

Analysing evaporators includes reviewing the control strategies and defrost cycles (Appendix 4). Solutions to improve the efficiency of evaporators include, but are not limited to:

- Controlling evaporator fans by installing VSDs.
- Removing external or internal evaporator fouling (e.g. dirt and oil, respectively) if the heat balance analysis determines that the evaporators are not working adequately.
- Maximising the evaporator temperature.
- For direct expansion systems, minimising the superheat settings or change from thermostatic to electronic expansion valves.
- Resetting the suction pressure/temperature for instantaneous loads.
- Optimising the evaporator defrosting cycle frequency and duration.

4.6 Compressor Analysis and Opportunities

Analysis of a refrigeration system's supply side includes a review of the suitability and controls of the compressors, sequencing of compressors and compressor maintenance practices (Appendix 4). Solutions to improve the efficiency of creating the refrigeration include, but are not limited to the following:

- Reviewing changes to the initial system design, which may have inherent inefficiencies.
- Reducing the pressure ratio across a compressor, where possible, by increasing suction pressure and reducing discharge pressure.
- Optimising multiple compressor control.
- Install a compressor economiser.
- Compressor suitability for base loads or low loads.
- Performing regular system maintenance.
- Reconditioning or replacing worn compressors.
- Installing compressors on multiple suctions for multiple temperature systems to meet low-stage loads.
- Opportunities for a VSD on the trim compressor.
- Installing a separate smaller system for after-hour loads, if the existing system is oversized and inefficient during after-hours operation.
- Replacing inefficient motors.
- The compressor operating most efficiently at the actual operating conditions should be preferentially selected in multi-compressor systems.

4.6.1 Economiser

A screw compressor can be economised by allowing the refrigerant to pass through two expansion stages and one compression stage. This is only effective for the cases where the compressor is loaded above 70%. The intermediate vapour is fed into a screw compressor via an economiser port. There are energy savings because the flash vapour formed at the intermediate pressure need not be compressed across the full pressure ratio range that it would have to be if a single stage compressor was used. By including an economiser, the system is able to provide more cooling capacity for low temperature loads.

Note that economising does not provide the full benefit of a two-stage refrigeration system.

One example of an economiser is shown in Figure 6, which is for an open flash economiser in a two-stage system.

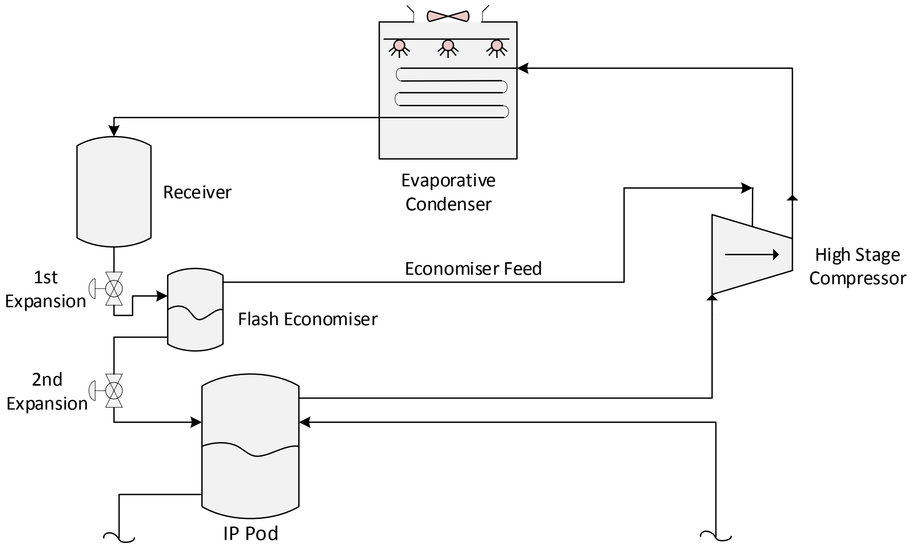


Figure 6: Open Flash Economiser in a Two-Stage System

4.7 Condenser Analysis and Opportunities

Analysis of a refrigeration system's heat rejection via condensers requires a review of the suitability and control of the associated fans and pumps, maintenance practices and operating setpoints (Appendix 4). Solutions to improve the heat rejection efficiency of the condensers include, but are not limited to:

- Minimising condensing temperature to improve the efficiency of the refrigeration cycle.
- Cleaning condenser surfaces to remove fouling and increase heat transfer.
- Controlling condenser fans based on the cooling load and ambient wet-bulb and dry-bulb temperatures.
- Controlling the condenser fans and pumps to synchronise with the operation of the compressors.
- Installing VSDs on condenser fans.
- Eliminating the accumulation of non-condensables in the refrigerant.
- Relocating condensers away from sources of heat.
- Clearing any blocked water nozzles to ensure proper water distribution over the coils.
- Ensuring air cooled and/or evaporative condensers do not have air short-circuiting.
- Eliminating liquid logging within condensers.
- Adding additional condensing capacity.

4.8 Network Analysis and Opportunities

Analysis of a refrigeration system network requires the determination of the refrigerant's delivery efficiency. This can be achieved with pressure and temperature measurements through different sections of the network.

Solutions to improve the efficiency of the refrigeration system network include, but are not limited to:

- Synchronising the refrigerant circulation pump to switch off when the compressors and evaporator fans are inactive.
- Reviewing changes to the initial system design, which may have inherent faults leading to excessive pressure drops. Focus on the suction and discharge lines.
- Identifying significant refrigerant pressure losses within the system, and water or secondary refrigerant pressure losses if the site has process cooling.
- Performing regular network maintenance.
- Identifying any improper pipe configuration through the piping and associated components and valves that result in large pressure drops and undesirable liquid logging.

- Adequately insulating all low temperature system components.
- Checking whether discharge (control) valves associated with pumps are partially closed most of the time. If so, consider trimming the impellor diameter or controlling the pump speed through a VSD.

4.9 Heat Recovery Analysis and Opportunities

Analysis of a refrigeration system's heat recovery opportunities involves determining the heat load of the site and current heat rejection associated with the refrigeration system. This requires the measurement of temperature and flow through different sections of the system. Heat recovery opportunities include using:

- Oil coolers
- Desuperheaters
- Condenser cooling water.

Heat recovered from any part of the system is typically used within the hot water generation system, such as preheating process/domestic water or preheating boiler feed water. Synchronising refrigeration heat recovery with heat demands on site can significantly reduce the cost to generate hot water. For example, an oil cooler and/or a desuperheater can provide low grade waste heat for the first stage of water heating, before being supplemented with higher grade process heat recovery, prior to entering a boiler (if there is a boiler at the site).

For base level assessments it may be difficult to determine the heat available for recovery without accurate measurements of flow, temperature and pressure, let alone calculate potential energy savings. Consequently, assumptions are often required, as well as auditing experience.

4.9.1 High Temperature Heat Pump

Often the temperature of the liquid from the desuperheater and/or condenser is not adequate for the process requiring this heat. The temperature of the liquid can be boosted by installing a high temperature heat pump. The high temperature heat pump effectively adds another stage of refrigeration whereby the gas from the higher stage of refrigeration would be taken into the suction of the high temperature compressor. The discharge from the high stage compressor would typically flow into a high pressure pot to cool the superheated gas. A dry suction line from this high pressure pot would then feed into the high temperature compressor. For ammonia heat pumps, the compressor can compress to a saturation temperature of up to 80°C. The gas would then enter into a condenser which would be cooled by the required process liquid that is being usefully heated.

4.10 Refrigerant

When recommending a refrigerant for a system, the efficiency and safety of the refrigerant needs to be determined. Refrigerants must comply with Standard AS/NZS 1677.2 to meet safety requirements.

4.11 Whole-system Considerations

Analysis of the refrigeration system may identify an efficiency opportunity in one part of the system that (if taken) will have an impact on the value of an opportunity in another part of the system.

The analysis needs to identify 'dependent' or 'mutually exclusive' opportunities across the whole system, to ensure that the most cohesive and well-specified recommendations are made to the client. Dependent and mutually exclusive opportunities need to be clearly stated.

The order of the savings opportunities (and therefore the sequence in which the opportunities are dependent) should consider the logical process of implementing demand efficiency opportunities before supply or network efficiency opportunities. The order of savings should consider the payback period on the opportunity and assume that opportunities with the shortest payback periods will be implemented before those with longer payback periods requiring significant capital investment.

For example, refrigeration systems reject large amounts of low grade heat, which can be heat sources to other processes on the client's site. Refrigeration system audits should include the identification of opportunities for the installation of heat recovery systems. If opportunities that are implemented reduce the cooling demand on the refrigeration system, this will therefore reduce the heat rejected by the system and influence the economics of heat recovery.

5.0 Audit Standard Report

A recommended report outline for an investment level audit is included in Appendix 7. This outline provides a specification of the content and structure of the report that should be generated by the refrigeration system auditor, following an audit conducted to this Audit Standard. The purpose of the specification is to assist the auditor to produce a concise, consistent and complete presentation of the findings, analysis, and recommendations arising from a refrigeration system audit.

Appendix 8 contains the recommended report outline for a base level audit.

6.0 Post-implementation and Continuous Monitoring

As discussed in Section 2.7, an audit should be followed by implementation of recommended corrective actions. The scope and nature of any post-implementation verification audit will have already been defined in the audit planning stage.

If a number of changes have been implemented throughout the system and if metering is available to record the total electrical consumption of the whole system, then monitoring can be performed for the refrigeration system. For whole system post-implementation monitoring of electricity usage, it is generally important for this to be relative to the refrigeration system benchmark. This enables the value of post-audit design or operations changes to be measured on an ongoing basis.

Alternatively, if a small number of changes have been implemented on large items, then they could be metered individually. An example of this is if a VSD is installed on a refrigeration compressor. In this case an energy meter could be installed for the machine with the VSD on only, and then compared with the historical energy consumption of the motor which will have been identified during the audit.

Continuous monitoring is recommended to operate the refrigeration system efficiently over time.

Appendix 1 — Site Information Form

Business Name	
Site physical address (Street, Suburb, City)	
Nature of site/business operation	

First day of onsite loggings	
Final day of onsite loggings	
Production during period of loggings	

Electricity Supplier	
Power factor correction equipment in use	
Delivered electricity cost per kWh	
Copy of electricity bills for the last 12 months	

Thermal energy type	
Thermal energy supplier	
Delivered thermal energy cost per kWh	

Site contact 1:	**Name**	
	Designation	
	Telephone (DDI)	
	Email	
Site contact 2:	**Name**	
	Designation	
	Telephone (DDI)	
	Email	

Comments:

Appendix 2 — Investment Level Data Collection Forms

Network Schematic	
System Reference	

Generation Information			
Refrigerant		Estimated Run Time	
Cooling End Uses		System Scheduling	
System Type	(e.g. DX, flooded evaporator, pumped, single/2 stage)		
Maintenance Practices			
Other Notes			

Demand Information (for each user)			
Open-door Duration		Insulation Type and Thickness (vapour barrier quality)	
Open-door Frequency		Space Dimension	
Size of Doors/Openings		Number of Lights	
Measured Velocities Through Doorways		Light Wattage	
Type of Protection at Doorways		Lighting Duration per Day	
Product Type		Equipment Loads	(e.g. processing equipment in Ready to Eat areas)
Product Temperature In		Number of People	
Product Temperature Out		Underfloor Heating Type	
Product Weight Flow per Day		Underfloor Heating Setpoint	
Infiltration		Air Pressure Difference between Refrigerated Space and Other Spaces	
Air Inside Refrigerated Space		**Air Outside Refrigerated Space**	
Dry-bulb Temperature		Dry-bulb Temperature	
Wet-bulb Temperature or Relative Humidity		Wet-bulb Temperature or Relative Humidity	
Other Notes			

Evaluator Information			
Type	(air, fluid cooled)	Refrigerant Pressure	
Make		Refrigerant Temperature In/Out (Refrigerant superheat if direct expansion)	
Model		Refrigerated Space Temperature Setpoint	
Number of Fans/Pumps		Fluid On/Off Temperatures	
Fan/Pump kW		Fins per Inch	
Speed as a Function over Time		Fouling*	
Number of Fans/Pumps Active		Load Control	(on/off, backpressure, VSD)
Fan/Pump Control		Defrost Type	
Energy Saving Opportunities		Defrost Frequency	
		Defrost Duration	
		Defrost Initiation and Termination	
		Melt Water Volume / Defrost Volume over Time	
Other Notes			

* A visual inspection of the evaporator should be made to check for fouling or inadequate defrosting.

Compressor Information			
Makes		Models	
Types of Compressors		Motor Sizes	
Suction / Discharge Pressures		Suction / Discharge Temps	
Multiple Compressor Control			
Unloading capability	(e.g. cylinder unloading, slide control, VSD)		
Compressor & Motor Type	(e.g. hermetic/semi-hermetic/open-drive)		
% Loading as a function of Time			
Other Notes			

Oil Cooler Information			
Oil Cooling Medium		Oil Temperature In & Out	
Oil Cooler Type (e.g. external)		Cooling Medium Temperature In & Out	
Heat Recovery Opportunity			
Other Notes			

Condenser/Cooling Tower			
Type	(air, water, evaporative)	Refrigerant Pressure	
Make		Refrigerant Temperature In/Out	
Model		Water Temperature In/Out (if Water Cooled)	
Number of Fans/Pumps		Air On/Off Temperatures and Relative Humidity (if Air Cooled)	
Fan/Pump kW		Water Treatment Used	
Number of Fans Active		Condensing Pressure Control	
Fan Control		Pump Control	
Air Short Circuiting		Fouling	
Liquid Logging Risk		Air Purging	(automatic or none)
Heat Recovery Opportunities			
Other Notes			

Network Information			
Refrigerant Pipework		***Cooling Fluid Pipework (if applicable)***	
Obtain Piping and Instrumentation Diagrams		Obtain Piping and Instrumentation Diagrams	
General Condition		General Condition	
Insulation Condition		Insulation Condition	
Refrigerant Circulation Pump Details		Circulation Pump Details	
Refrigerant Pump Control		Circulation Pump Control	
Difference in temperature between the lowest temperature refrigerated space and compressor suction (LP loop, IP loop)			
Obvious restrictions or design faults in the piping resulting in large pressure drops			
Obvious pressure drops over regulating valves or other fittings			
Other Notes			

Appendix 3 — Base Level Data Collection Form

Refrig. System		**Description**	

Electrical Energy Use Details						
Delivered Electricity Cost			Cents per kilowatt hour			
Equipment ID	***Make/Model***	***Rated kW (elec)***	***Load Factor****	***Hours of Operation*** *(e.g. 0800-1700)*	***Annual Run Hours***	***Annual Energy Consumption***
Total Electrical Energy Use						
Annual Electrical Energy Operational Cost						

* Load Factor: Percentage of full load at which the machine typically operates at on average

Thermal Energy Use Details (if Heat Recovery Opportunities Identified)						
Fuel Type		Fuel Cost				
User ID	***Rated kW (thermal)***	***Thermal Efficiency***	***Load Factor***	***Hours of Operation***	***Annual Run Hours***	***Annual Energy Consumption***
Total Thermal Energy Use						
Annual Thermal Energy Operational Cost						

Total System Energy Use Data	
Total Refrigeration System Energy Usage (kWh/year)	
Total Refrigeration System Energy Cost ($/year)	
Relevant Production Measure (e.g. units produced)	
Estimated Annual Production Throughput	
Estimated Refrigeration System Energy Intensity (REI)	

Appendix 4 — Energy Efficiency Opportunities Checklist

	Assessment Checklist	Potential for Efficiency Improvement				
	Efficiency Opportunity Element	**N / A**	**LOW**	**MED**	**HIGH**	**Further Comments**
DEMAND	Door management and protection					
	Product heat load reduction					
	Evaporator fan heat load reduction					
	Equipment heat load reduction					
	Lighting heat load reduction					
	System user isolation					
	Optimise evaporator defrost cycles					
	Insulation and vapour barriers					
	Peak demand control					
EVAPORATOR	Optimising evaporating temperature					
	Optimise evaporator defrost cycles					
	Reset suction pressure for instantaneous loads					
	Evaporator fan control					
	Evaporator fouling					
	Optimise superheat					
	Refrigerant pump control					
COMPRESSOR	Select appropriate refrigerant pressure for end user					
	Reduce pressure ratio across compressor					
	Optimise multiple compressor control					
	VSD trim compressor potential					
	System scheduling and control					
	Multiple suctions for multiple temperature levels					
	Compressor suitability					
	Oil cooler					
	Heat recovery opportunity – oil cooler					
	Compressor economiser potential					
	Separate smaller system for after-hour loads					
	System maintenance practices					

COMP. (cont.)	Hours operated since last compressor maintenance/ overhaul					
	Changes to initial system design					
	Motor efficiency					
	Oil pumping					
CONDENSER	Minimise condensing temperature					
	Condenser fan control					
	Condenser pump control					
	Condenser fouling					
	Install additional condensing capacity					
	Air cooled condenser/evaporative condenser/cooling tower air short circuiting					
	Non-condensable accumulation					
	Heat recovery opportunity — desuperheater					
	Heat recovery opportunity — cooling water					
NETWORK	Automatic purger					
	System pressure losses					
	Insulation of low temperature pipework					
	Circulation pump control					
	Pipe configuration					
	Changes to initial network design					
	Network maintenance practices					
	Power factor correction					

Type	Initiative
DEMAND	**Door Management and Protection** Air infiltration into refrigerated spaces through open doors and poor seals significantly increases the cooling demand on refrigeration systems. This is important for both small and large storage systems. The heat gain increases refrigeration loads and the moisture increases the frequency of evaporator defrosting. The analysis needs to identify how often and how long doors are left open, in order to recommend the most appropriate door management and/or protection method to reduce air infiltration. Methods to reduce this include educating staff and installing strip curtains, automatic doors with sensors, air curtains, air locks etc. Loading dock seals are important. Incorporating seal inspection and repair as part of routine maintenance ensures that seals are kept in good condition. There may also be better alternative doorway sealing methods suitable for retrofit.
	Product Heat Load Reduction If product is too warm before it is chilled or frozen, the load on the refrigeration system will be higher than necessary. It needs to be investigated whether product can be pre-cooled prior to entering refrigerated spaces. It should also be investigated whether product is being adequately prevented from pre-heating e.g. left in ambient temperature before loading.
	Evaporator Fan Heat Load Reduction Heat generated by the fan motors is an additional heat load that the refrigeration system has to cool. This can be reduced by installing better quality fans, more efficient motors, VSD motors and having better air distribution design.
	Equipment Heat Load Reduction Equipment within refrigerated spaces contributes to the heat load. Equipment loads should be reduced by installing more efficient motors and/or placing equipment outside of the refrigerated space.
	Lighting Heat Load Reduction Installing energy efficient lighting in refrigerated spaces will reduce the amount of heat being generated.
	System User Isolation Ensuring all users of chilled water and/or refrigerant are isolated when not required, e.g. when an industrial machine that uses chilled water for cooling is taken off-line, it should be isolated from the chilled water circuit. This reduces the heat load on the refrigeration system as well as potential pumping costs.
	Optimise Evaporator Defrost Cycles The frequency and duration of evaporator defrost cycles should be optimised to reduce the amount of heat that is used during defrost. This will therefore reduce the heat load on the refrigeration system.
	Insulation and Vapour Barriers Heat transfer through poorly insulated surfaces can account for a large proportion of a refrigeration system's load. Obvious signs of inadequate insulation are water or ice patches on the outside of the ceiling of refrigerated spaces. The thickness and quality of the insulation may have been inadequate when it was installed, or it could have broken down over time. Penetrations into refrigerated spaces such as structural steel act as thermal bridges and are undesirable. Roof spaces above refrigerated spaces may get hot and should be adequately ventilated. Thermographic photography should be used to identify insulation opportunities. Insulation should be repaired where applicable. A common issue is when the vapour barrier on the outside of the insulation is damaged, allowing water to condense and freeze inside the insulation.
	Peak Demand Control This includes opportunities related to the shedding or shifting of electrical loads from peak demand periods where the electricity supply costs (energy and/or network costs) are higher than during other periods. An example is to switch off freezers when not in use, but this must not impact on production.

EVAPORATOR	
	Optimising Evaporating Temperature Keeping the evaporating temperature as high as possible can be achieved manually by changing it seasonally or automatically. There should not be an excessive temperature difference between the evaporating temperature of the refrigerant and the temperature which is actually required by the refrigeration end user. If the evaporator load is controlled by a liquid solenoid, then the percentage of the time that the solenoid is open will indicate whether the suction pressure is too low. Similarly, if the load is controlled by a back pressure valve on the discharge of the evaporator, the amount at which the valve is not fully open over time could determine if the suction pressure can be increased.
	Optimise Evaporator Defrost Cycles The frequency and duration of the defrost cycles should be matched to the load. Moisture in humid air condenses on evaporator coils, freezes and forms an ice layer which reduces the heat transfer efficiency and impedes air flow through the evaporator. Defrosting removes the ice, though this takes energy. The optimum defrosting strategy keeps defrosts to the minimum necessary to keep evaporators free of ice. Typical defrosts are either too long in duration or occur too frequently. The frequency and duration of the defrost cycles should be adjusted for summer and winter, since infiltration of warm and humid summer air into refrigerated spaces will cause the evaporators to ice up more frequently than in winter. The melt water captured will give an indication of the ice to be removed. The volume of melt water over time indicates whether the defrost period is too long. The time taken for the ice to melt from the entire surface of the coils should not be significantly less than the defrost duration. Defrost cycles are typically activated by either: • Timers (this is most often used, but can also be the most inefficient). • Air pressure differential across the evaporator. • Suction temperature or pressure of the compressor, if the compressor only serves one evaporator. • Direct ice sensors (can be insensitive). Defrost sensors that detect when to terminate defrosts help to achieve good defrost performance. Defrost cycles are often initiated by timers and terminated by timers, pressure sensors or temperature sensors. Note that large industrial systems typically only use timers for defrosting. Where supply air and return air ducts exist (such as with low temperature supermarket display cases) it is important to ensure ducts and air diffusers are clear of ice build up when optimising defrost duration.
	Reset Suction Pressure for Instantaneous Loads If instantaneous low temperature loads are placed on the refrigeration system (such as a spiral freezer at -40°C) then the suction pressure should be reset to provide the required cooling for this load. Once cooling demand drops, the evaporator and compressors should adjust back up to a higher temperature to provide cooling for the other refrigerated spaces.
	Evaporator Fan Control Evaporator fans circulate air within a space so that heat is removed from the space via evaporator coils. The energy the fans consume is also an additional heat load. VSDs slow the fans when cooling demand is low, saving power. However it is essential to maintain good air distribution so minimum fan speeds may be necessary. To get maximum benefit, all fans in a refrigerated space should be controlled together rather than individually.
	Evaporator Fouling Evaporator fouling can cause high pressure drops and low flows. This results in inefficient evaporator operation, reduced heat transfer effectiveness and higher loads on circulation pumps on both sides of the heat exchanger. The evaporators need to be visually inspected for fouling.
	Optimise Superheat Too much superheat reduces the performance of the evaporator. High superheat also reduces the performance of the compressor and raises the discharge temperature. Too little superheat reduces the stability of the expansion valve and increases the risk of liquid carry-over to the compressor suction (potentially resulting in mechanical damage to the compressor). Superheat therefore requires optimisation. For thermostatic valves, superheat of 4 to 7°C is the typical minimum for valve stability. For electronic expansion valves this can reduce to 2 to 4°C.
	Refrigerant Pump Control Savings can be made by ensuring that refrigerant pumps are switched off with the evaporator fans and/or adjusted to match cooling load. There may be minimum flow requirements, in which case a pump's speed can be reduced via a VSD. There will be direct savings from the pump power consumption and indirect savings from the pump heat load.

COMPRESSOR	
COMPRESSOR	**Select Appropriate Refrigerant Pressure for End User** The refrigerant pressure/temperature should only be low enough to just cope with the refrigeration load and provide the required user temperatures. For example, the holding temperature of a storage area may be lower than required and therefore use more energy and incur more efficiency penalties than at a higher temperature. The system's compressor suction pressure should be set as high as possible. If the refrigeration system is two-stage, then some refrigerated spaces could be supplied by IP refrigerant rather than LP refrigerant. Refrigerated spaces that are cooled by IP refrigerant have a higher COP than those using LP refrigerant, and therefore require less energy to refrigerate.
	Reduce Pressure Ratio Across Compressor Reducing the pressure difference between the condensing and suction pressures will reduce energy consumption by the compressor.
	Optimise Multiple Compressor Control VSD-controlled screw compressors lose little efficiency when turned down and are ideal for regulating refrigeration output with non-VSD-controlled compressors running at full load to meet the base load. Efficiency is maximised by controlling multiple compressors so that, as much as possible, larger screw compressors run fully loaded and capacity is trimmed by partly loading the smallest screw, reciprocating or VSD-controlled compressors.
	VSD Trim Compressor Potential Most refrigeration screw compressors modulate their capacity using a slide valve. At high turn-down, the compressor's part-load efficiency drops from 100% down to 10-30% (depending on the pressure ratio of the compressor). VSD-controlled screw compressors lose little efficiency when turned down and are ideal for regulating refrigeration output with non-VSD compressors running at full load to meet the base load. For screw compressors a VSD should control down to about 50% of full speed and then the slide valves can be adjusted further (If the compressor speed is reduced to less than 50% of full speed, the tip speed is often below design conditions and the internal leakage can be high).
	System Scheduling and Control This relates to the manual or automatic scheduling of supply components such as compressors so that they only operate when required. Control methods include timer control or temperature sensors.
	Multiple Suctions for Multiple Temperature Levels If cooling is required at two different temperatures (i.e. for freezing and for chilling) running the entire system at the low pressure needed for freezing handicaps the system's efficiency. Consider installing multiple suctions for meeting the different low-stage loads.
	Compressor Suitability For a screw compressor, the volume ratio has to match the pressure ratio to obtain maximum efficiency. Some models will be more efficient than others for the same pressure ratio due to a difference in their internal volume ratio. Some compressors are well suited to high base loads, while others are better suited to act as trim compressors or at lower loads. The volume ratio should be checked, and if possible adjusted, to suit the required pressure ratio. Depending on the compressor, the volume ratio will be fixed, manually adjustable or automatically adjusted. Manufacturer design documents typically only provide data for design operating conditions, so manufacturer-supplied computer programs with the particular data for the machine should be used where possible.
	Oil Cooler Check whether the compressor has external oil cooling (by water or thermosyphon). Oil cooling by liquid refrigerant injection into the body of the screw machine is a very inefficient process.
	Heat Recovery Opportunity — Oil Cooler Oil provides lubrication for the compressor and is heated as the refrigerant is compressed. The oil needs to be cooled to approximately 50°C prior to re-entering the compressor, in order to provide optimal lubrication. Oil coolers produce low grade waste heat that can be used to preheat water used for producing hot water. The heat recovery opportunity will depend on the demand for hot water at the site.
	Compressor Economiser Potential It is possible to install economisers on some single-stage screw compressors to bring their efficiency level up towards the level of two-stage compression. Screw refrigeration compressors have economiser ports to allow compression from an intermediate pressure, which improves the system's thermodynamics and efficiency.

COMPRESSOR (cont.)	**Separate Smaller System for After-Hour Loads** There may be potential to install smaller systems for after-hour loads if a large system operates particularly inefficiently during these periods because it is designed for much larger loads.
	System Maintenance Practices This refers to the regular maintenance of the system so that components operate as designed. This includes minimising refrigerant leakage, ensuring the correct charge and optimising air purgers.
	Hours Operated Since Last Compressor Maintenance Records should be available on the number of hours operated since the last compressor overhaul. If the compressor has not been overhauled as part of a regular maintenance program then the machine could be worn. Worn compressors do not seal adequately and leak refrigerant from the high pressure side to the low pressure side of the chamber.
	Changes to Initial System Design This includes opportunities related to changes that have occurred in the refrigeration system design since original installation, such as compressor replacement to meet new demands. As systems are modified, their inherent efficiency may decrease as a result and the piping network may be overloaded.
	Motor Efficiency Burned-out motors should be replaced instead of rewound at failure. This is particularly true for compressor motors, which account for a large proportion of total system energy consumption.
	Oil Pumping Check whether the compressor has an oil pump or if it depends on the differential between the discharge and suction pressure of the compressor to “pump” the oil. The latter method limits reducing the discharge pressure.
CONDENSER	**Minimise Condensing Temperature** Decreasing the condensing temperature, assuming there is capacity in the evaporative condensers or cooling towers, directly affects the compressor discharge pressure/temperature and therefore the efficiency. Keeping the condensing temperature as low as feasible can be achieved manually by changing the condensing temperature seasonally or automatically through temperature sensors, e.g. maintaining condenser temperature at 5-15°C above the wet-bulb temperature. Reducing the condensing temperature will increase power consumption of the evaporative condenser fans or cooling tower fans. A compromise will need to be determined between the two competing effects.
	Condenser Fan Control The condenser water temperature depends on the cooling load, the air temperature and humidity, and the fan speed. For air-cooled condensers, evaporative condensers and cooling towers, a constant fan-speed will result in excessive fan power during times of low demand, air temperature, or humidity. A temperature switch or VSD turns off or slows the fan(s) when possible, saving power and ensuring more stable temperatures.
	Condenser Pump Control Savings can be made by ensuring that condenser pumps are switched off with the condenser fans. There may be minimum flow requirements, in which case a pump's speed can be reduced via a VSD. There will be direct savings from the pump power consumption and indirect savings from the reduced heat load.
	Condenser Fouling Examine the water treatment of the evaporative condenser or cooling tower to ensure growth and scaling is eliminated. Cooling water lines may develop fouling, especially when cooling towers are used for cooling. This causes poor heat transfer, high pressure drops and low flows, resulting in inefficient condenser operation and higher loads on circulation pumps.
	Install Additional Condensing Capacity If the condensing capacity is inadequate (which would show up by having the condensing pressures higher than the design) and if the condensers are operating correctly (i.e. they have been checked for fouling and the accumulation of non-condensable substances) then additional condensing capacity is required. Additional condensing capacity can be added by either adding another condenser, removing the oil heat from the condenser by using the heat elsewhere, and/or by adding a desuperheater.

CONDENSER (cont.)	**Air short circuiting** Air cooled condensers , evaporative condensers and cooling towers should be checked to ensure that the air is not short circuiting: This can occur if the condensers are placed close buildings etc.
	Non-Condensable Accumulation The refrigerant temperatures and pressures measured in the condenser need to be compared to the thermodynamic properties of the refrigerant. If the measured properties differ significantly from what is expected, there may be non-condensable substances (e.g. air) in the refrigeration system. This will reduce the efficiency of the system e.g. the condenser performance is lower than expected.
	Heat Recovery Opportunity — Desuperheater Refrigerant discharged from the compressor is typically superheated by 20°C to 70°C above the condensing temperature. A desuperheater (heat exchanger) uses this energy to typically heat water. There must be a demand for hot water at the available temperature, and the payback period depends on the current method and amount of water heating. Hot water storage may be required if the demand for hot water is not at the same time than when refrigeration occurs. In systems that are limited by condenser capacity, the use of a desuperheater can also result in a compressor efficiency gain through a reduction in discharge pressure due to increased condensing capacity.
	Heat Recovery Opportunity — Cooling Water Similar to the desuperheater, discharged cooling water can be used as a low-grade source of heat. This can be achieved via a heat exchanger prior to the cooling tower.
NETWORK	**Automatic Purger** Non-condensable gases in refrigerants such as air will increase the head pressure of the compressors and thus increase the power drawn by the compressors. An automatic purger installed in the right location(s) will purge the refrigerant of these gases.
	System Pressure Losses Losses in refrigerant pressure – related to the throttling of flow or undersized pipes and fittings – affect the suction and discharge pressures, which have a significant effect on compressor energy efficiency.
	Insulation of Low Temperature Pipework Ensuring the effective insulation of chilled water and/or refrigerant lines will mean that the chiller energy demand and costs are reduced.
	Circulation Pump Control Savings can be made by ensuring that the compressor and cooling tower refrigerant circulation pumps are switched off. There will be direct savings from the pump power consumption and indirect savings from the reduced heat load, requiring less energy to remove it.
	Pipe Configuration Undersized pipes, complex pipe layouts and large distances all increase the pressure drop in the system. Large networks will also result in high distribution losses.
	Changes to Initial Network Design This includes opportunities related to changes that have occurred to the network layout since original installation, e.g. changes in pipework to supply more users. As systems are modified, their inherent efficiency may decrease as a result.
	Network Maintenance Practices This refers to the regular maintenance of the network and heat rejection system so that systems operate efficiently as well as reliably. This includes cleaning condenser surfaces regularly, cleaning evaporator tubes or surfaces and ensuring cooling liquid and/or refrigerant leaks as well as air infiltration are kept to a minimum.
	Power Factor Correction Power factor at the main switchboard should be at least 0.95. If not, power factor should be corrected. However, if the electric lines to the compressor area are overloaded then power factor correction should be applied at the compressor area switchboard.

Appendix 5 — Measurement Accuracy Implications

Error can be minimised by taking as many relevant measurements as practical. For example, the operation of a refrigeration system could be verified by taking electrical, temperature and pressure loggings of the compressor, evaporator and condenser or cooling tower to determine the average load.

Given that accuracy is a combination of a number of variables, the auditor needs to be aware what the main sources of inaccuracy are for the measurements and system concerned. When considering an overall audit accuracy requirement, the effect of cumulative measurement uncertainties must be taken into account. The calculation of uncertainty depends on the type of mathematics operation being performed.

Percentage Error

If a data logger used for electrical power measurement has a rated accuracy of ±0.01kW and an average absolute measurement of 12kW has been recorded, the maximum percentage error would be:

(Eqn. 1)

Alternatively, if the data logger stated an accuracy of ±0.2%, the term would simply equal 0.2%.

Addition/Subtraction

The sum of the square of the uncertainties needs to be used if uncertainties are added or subtracted within an equation. The following example for energy meter readings demonstrates this:

(Eqn. 2)

Where: = compressor power (kW)

= incoming power (kW)

= miscellaneous power (kW)

The absolute uncertainty for this equation can be expressed as:

Absolute uncertainty =

(Eqn. 3)

Where is the 'maximum inaccuracy' possible for a given absolute variable and is the number of uncertainties in the equation.

The absolute uncertainty of is therefore:

Multiplication/Division

Fractional uncertainties need to be used in the case of multiplication or division of uncertainties. As an example, the components of the heat transfer equation are used below to demonstrate how to assess the effect of each component's accuracy on the overall accuracy:

(Eqn. 4)

Where: = heat transfer (kW) = heat transfer medium mass (kg)

= time (s) = specific heat capacity (kJ/kg°C)

= change in temperature inlet to outlet (°C)

The total fractional uncertainty for this equation can be expressed as:

Fractional uncertainty =

(Eqn. 5)

Where is the 'maximum inaccuracy' possible for a given absolute variable and is the number of uncertainties in the equation.

For Equation 3, the total fractional uncertainty is therefore:

(Eqn. 6)

Note that is the error between two temperature measurements, to avoid confusion with , which denotes a difference in temperature.

Appendix 6 — Glossary of Terms

Air Dew Point – Temperature at which air moisture will begin to condense at a given pressure.

Annual Run Hours – The total hours each year that a piece of equipment is operating.

Baseline Consumption – Estimated refrigeration system annual energy consumption prior to intervention.

Condenser – A device which rejects heat from the refrigerant, causing the refrigerant to change phase, from vapour to liquid.

Condensing Unit – An integrated unit including a compressor, condenser, condenser fan, motor, receiver and controls.

EMO – Energy Management Opportunity.

Evaporator – A device for heat transfer from the product or cooling medium (e.g. air) to the refrigerant, causing the refrigerant to change phase from liquid to vapour or increase in temperature (secondary refrigerants).

Expansion Valve – A device that reduces the pressure of the refrigerant by allowing the fluid to expand and move through an orifice.

Fan – A mechanical device used to impart motion on air. A fan moves large amounts of air with low increase in pressure. Fans are addressed in the separate Fan System Audit Guideline.

Gauge Pressure – The pressure measured by a gauge. Note that the value is relative to atmospheric pressure and is therefore 1 atmosphere less than an absolute pressure measurement.

Heat Exchanger – A system component through which heat is transferred from one medium to another.

Heat Recovery – Any form of reuse of heat that can be considered a waste product from another process.

Heat Transfer – Heat transmission between materials via conduction, convection or radiation.

HP Refrigerant – High pressure refrigerant (at the discharge pressure of the high stage of the refrigeration system).

Insulation – A physical barrier to heat transfer used to minimise heat loss. A good insulating material can be considered a poor transmitter of heat.

IP Refrigerant – Intermediate pressure refrigerant (at the low-stage discharge pressure and high-stage suction pressure, if the system utilises a two-stage cycle).

Isentropic Compression – The compression path with no change in entropy (e.g. following an isentropic line on a Mollier diagram).

Key Business Driver – The business outcomes or requirements against which the refrigeration system's energy consumption is measured for benchmarking and monitoring purposes. This is used to determine the Refrigeration Energy Intensity (REI) of the system. An example of this may be production (kg).

kVA – kilovolt-ampere. Common unit for apparent power, which is the total power that appears to be flowing from a source to a load (usually based on current and voltage measurement).

kW – kilowatt. Common unit for real power, which is the actual net power that is flowing from a source to a load.

Load Duration Curve – A graph depicting the electrical or refrigeration load distribution of a system over a period of time.

LP Refrigerant – Low pressure refrigerant (at the suction pressure of the low stage of the refrigeration system).

Modulating Control – A mode of automatic control in which the action of the final control element is related to the deviation from the setpoint of the controlled medium.

Motor Efficiency – The energy delivered from the motor shaft divided by the energy delivered to the motor.

Peak Load – The peak power consumption of a site. This often determines the demand charges incurred by the site and should be taken into account when considering the operating times of refrigeration systems.

Power Factor – Ratio of real power to apparent power.

Pressure Ratio – Ratio of the absolute discharge pressure of a compressor to its absolute suction pressure.

Pump – A device that moves liquid by mechanical action.

Refrigeration – In the context of this document, refrigeration for a commercial or industrial application applies to refrigerated spaces from -45°C to +15°C and includes liquid and process chilling.

Refrigeration Compressor – A mechanical device to increase the pressure of the refrigerant by an absolute pressure ratio of over 1.2.

Refrigeration Compressor Efficiency – Ratio of the isentropic energy of compression to the compressor input power.

Refrigeration System – The system that includes refrigeration compressors, evaporators, condensers, pumps, fans, valves and refrigerated spaces.

Refrigeration System Energy Intensity (REI) – The energy intensity of a refrigeration system with respect to a related key business driver, e.g. kWh per kg of production.

Refrigeration User – Any device relevant to the business operation, that requires the use of refrigeration to perform an appropriate task, such as products being frozen in blast freezers.

SCADA System – Supervisory Control and Data Acquisition system.

Shaft Input Power – The power delivered to the shaft of a compressor, pump or fan.

On/Off Control – The control method where demand is met by switching the controlled device on or off.

System Boundary – A boundary defined by the auditor, which encompasses the refrigeration system components and refrigerated applications to be analysed.

Trim Refrigeration Compressor – A compressor that meets the variable component of refrigeration demand. This is as opposed to base-load compressors which operate at their full capacity.

Two-Stage Cycle – A refrigeration system that involves two vapour compression stages and two liquid expansion stages to achieve cooling at two different temperatures.

Valve – A device that directs flow into an alternative path or that restricts flow, and which is typically used to shut off flow completely.

Variable Speed Control – Control method where the speed of the device is varied to meet the demand.

Variable Speed Drive (VSD) – A variable speed drive (VSD) is a system for controlling the rotational speed of the electric motor through adjusting the electrical frequency supplied to the motor. These drives can be used to match the air flow demand over the evaporators or the refrigeration demand on the compressors (for example).

Appendix 7 — Recommended Report Outline – Investment Level Audit

This appendix provides a recommended outline of the structure and contents of the report used for reporting the process, findings and recommendations from an investment level audit, conducted according to this Refrigeration Systems Audit Standard.

The following describes the recommended structure and content of the audit report, section by section.

Executive Summary

Provide a summary of the objectives, scope, findings and recommendations. The executive summary should highlight the key recommendations for the client to action and a rationale for the action that is concise, understandable and compelling, recognising the client's decision-making processes.

A table with the details of the current and expected energy consumption and cost at the site following the implementation of the identified energy management opportunities (EMOs) should be included, as shown in Table 0.1.

Table 0.1 – Summary of Annual Energy Usage

	Annual Electricity Use (kWh)	Annual Thermal Fuel Use (kWh)	Energy Use Benchmark (kWh/output)	Annual Energy Cost ($)	Energy Cost Savings ($)	Capital Cost ($)	Simple Payback (years)
Current							
If T1 implemented							
If T1 & T2 implemented							
If T1, T2 & T3 implemented							

The executive summary should also include tables presenting the identified EMOs for each of the T1 (payback less than 1 year), T2 (payback between 1 and 2 years) and T3 categories (paybacks greater than 2 years). Examples of these tables are shown in Tables 0.2, 0.3 and 0.4.

Table 0.2 – T1 EMOs (payback less than 1 year)

EMO	Description	Savings (kWh)	Cost Savings	Capital Cost	Payback Period
x.x					
x.x					
x.x					
Total					

Table 0.3 – T2 EMOs (payback between 1 and 2 years)

EMO	Description	Savings (kWh)	Cost Savings	Capital Cost	Payback Period
x.x					
x.x					
x.x					
Total					

Table 0.4 – T3 EMOs (payback greater than 2 years)

EMO	Description	Savings (kWh)	Cost Savings	Capital Cost	Payback Period
x.x					
x.x					
x.x					
Total					

A. Business Context

This section should cover basic information about the business and the objectives and scope of the audit.

Basic information

Include the following:

- Identity of the client and site location for which the audit is performed.
- Date of the refrigeration systems audit.
- Name of the client manager and other key personnel interfacing with or assisting the refrigeration system audit.
- Name, credentials and contact details of the refrigeration system auditor.

Site operating characteristics

Describe the operating characteristics of the site:

- A brief outline of the current operations of the plant, with a description of the main site activity that the refrigeration systems are required to support.
- The effects of any expected future changes to the nature or volume of the site activity that may have an effect on the site refrigeration system requirements.

Objectives and scope of the audit

Describe the following:

- The objectives of performing the audit. For example, it may be to provide the client's management with a general understanding of areas of potential (as would be expected from a base level audit) or it may be to support a capital expenditure proposal on a substantial refurbishment or redesign.
- The scope of the audit (all or a selection of systems at the site).
- Any useful background to the objectives and scope, including any prior scoping work and key clauses from any agreement between the client and the auditor.

Note: Where there is more than one independent refrigeration system on a site, Sections C, D and E within this Appendix should be repeated for each system.

B. Tariff Review

Include a tariff review for electricity, and also for the heating fuel used at the site if heat recovery EMOs are identified during the audit. The tariff review for electricity needs to describe the following:

- The type of electricity contract used at the site (e.g. FPVV, TOU, Hedged or Spot).
- Tabulated costs of the variable and fixed charges associated with the electricity supplied to the site.
- If the client is Time of Use, then a table of charges for each billed period across 12 months is useful for identifying periods of high and low cost.

When calculating the electricity savings for EMOs, only the variable portion of the electricity costs must be used.

C. Refrigeration System Overview

Include a high-level description of the system, identification of the business drivers and the means by which the audit results can be extrapolated to show annual operating characteristics.

Description and requirements

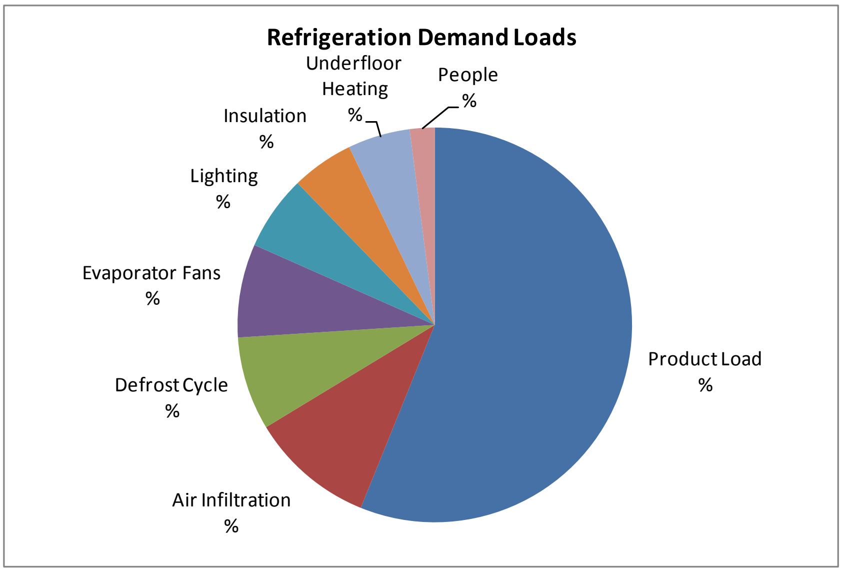
Include a description of the refrigeration system and its configuration, with reference to schematic drawings in an appendix to the report.

Describe the requirements that the business expects from the audit, including the following:

- A description and quantification of energy consumption throughout the system. Pie charts are generally useful in showing these quantities.
- A description and quantification (temperature, pressure) of what the refrigeration system needs to deliver to enable the business to operate efficiently.
- Identification of the site activity (e.g. production output or raw material input) that will be used as the key driver of refrigeration system use and will be used in the energy intensity measure for the refrigeration system.
- Identification of whether the refrigeration system requirements can be characterised as constant demand, multi-stage demand or variable demand.
- Information on the operating profile of the main site activity (e.g. volume of production), showing weekly and monthly/seasonal profiles.
- Any relevant benchmark information that may be available from site history or from intercompany comparisons on the refrigeration system's energy intensity.
- A description of any management policies or practices (e.g. safety or community matters) that influence the refrigeration system design or operational requirements.

Refrigeration demand loads

Provide a summary of the refrigeration demand loads placed on the system, as described in Section 4.2. For example:



Baseline energy intensity

This involves quantification of the relationship between the site activity (e.g. production output or raw material input) identified as the key driver of the refrigeration system and the system's electricity usage, using the daily data collected during the audit period.

This should describe the following:

- Daily site activity driving the refrigeration system energy usage.
- Daily kWh usage from the refrigeration equipment data-loggings or other measurements taken during the audit.
- The audit-period average and (where feasible) each day's value of the refrigeration system electricity intensity value (the baseline REI) for the period of the audit.

Having each day's value of the REI relationship may enable the effect of variations in activity level on the REI to be quantified and included in any subsequent analysis of the system, where the activity level is different from the average during the audit period. The relevance of the individual day's REI figures will be dependent on the driver and the ability to obtain activity levels of sufficient accuracy on a daily scale. Weekly or seasonal variation in the REI should also be considered.

If the client considers the activity figures are too commercially sensitive for inclusion in the report, include only the baseline REI figures.

D. Audit Measurement Methods

This section should cover the measurement methods used during the audit and identify (and rationalise) any variations between the actual measurement methods and those recommended in the Audit Standard.

Energy usage measurement

Include a description of electricity and fuel measurement methods used for the audit period, including any metering installed for subsequent (post-implementation) performance monitoring and the extent of any reconciliations performed between temporary and permanent meters.

For the refrigeration system involved, describe the following:

- The metering and data recording methods used, and the units measured.
- The refrigeration compressor motors logged.
- Other ancillaries logged.
- The period(s) and duration(s) of the measurements.

Demand duration curves are useful ways to describe and assist analysis of the system demand.

Energy cost measurement

Describe the method of quantifying the unit cost of electricity or fuel as appropriate for valuing any reduced consumption resulting from implementing a recommendation.

Costs should be based on future price expectations, and for electricity recognise the fixed and variable (per-kWh) components of delivered electricity prices. Where the client is subject to time-of-use and/or peak demand pricing, consideration should also be given to the time periods in which the systems operate, and therefore in which any energy savings are likely to occur. These considerations are most relevant when the audit results are to be used for investment proposal purposes.

Refrigeration system performance measurement

Describe the measurements used to estimate refrigeration loads and the performance of the refrigeration system (e.g. pressures, temperatures, flow rates etc).

Heat load measurement

Provide the methods used to quantify the heat loads.

Estimates of implementation costs

Provide the method or methods used to estimate the costs of implementing the actions included in the recommendations. This should include the following:

- The sources of the cost estimates.
- The level of accuracy that can be expected.
- Whether or not any preferred suppliers are involved.

E. Audit Findings

For each of the systems within the scope of the audit, this section should describe, analyse and quantify efficiency opportunities in a logical sequence from demand, to the network, through to supply. The subheadings should reflect these three main areas of the system. The EMOs outlined in Appendix 3 should be used as the basis for the recommendations made within this section.

Discussion of opportunities for change should include consideration of other viable options along with the recommended action.

For each Energy Management Opportunity, include the following:

- A description of the present condition or configuration of the equipment which the EMO applies to.
- A description of the efficiency opportunity.
- Transparent calculations of the energy and other savings potential.
- A cost estimation of implementing the proposed action.
- A simple payback period (or other net benefit measure), as applicable to the audit scope/accuracy requirement.
- Identification of any alternatives to the recommended action.
- Identification of dependencies, where a particular recommendation may be dependent on the implementation of some other recommendation or other plan.

Each EMO should be concluded with a table showing the energy savings, cost savings and payback for the proposed opportunity. For example:

Electricity Savings		Fuel Savings		Total Savings	Cost	Payback
25,000 kWh	$ 2,800	0 kWh	$ -	$ 2,800	$ 4,000	1.4 years

The detailed cost-benefit calculations that support each recommendation should be included as part of an appendix.

F. Ongoing Performance Monitoring

In this section of the report, consider and recommend what ongoing refrigeration system performance measurement systems should be put in place by the client. Measuring the electrical consumption of the refrigeration system on an ongoing basis enables the client to understand the effects of any changes made. It should also ensure that:

- The savings being targeted by the changes are truly captured.
- Timely corrective actions are taken to rectify identified inefficiencies.

The recommendations made regarding the locations of ongoing electricity measurements should be influenced by the results from the metering during the audit.

Section 2.7 and 6.0 of the Audit Standard outlines the options for ongoing electricity usage metering.

G. Appendices

The appendices should include the following:

- A schematic of the refrigeration system(s).
- Audit data records, including relevant pressure, temperature or electrical loggings.
- How heat loads in the refrigerated spaces were estimated.
- Heat gain reports containing thermal images taken while onsite (if applicable), along with detailed descriptions of the location of each surface and estimated heat loss.
- Cost-benefit details of options and recommendations.

In relation to the cost-benefit details, particularly where the audit will be used to support business investments, the relevant appendix should provide a summary of the data and calculations performed for each option and recommendation.

In addition, this should be accompanied by the following any supplier or installer quotations that support the implementation cost estimates, and any assumptions that could materially affect the accuracy of the payback period.

Where there are several options for the same outcome, clearly highlight these options as being mutually exclusive.

This level of detail can be important to the subsequent development of an investment proposal.

Appendix 8 — Recommended Report Outline – Base Level Audit

Executive Summary

Briefly describe the following:

- The objectives and scope of the base level report.
- The discrete systems that have been investigated during the base level energy assessment.

Briefly summarise:

- The condition of each system.
- The potential initiatives that could be implemented or further investigated.

Provide a summary of annual energy usage and tables of EMOs, such as Tables 0.1, 0.2, 0.3 and 0.4 in Appendix 6.

A. Business Context

Basic information

Include relevant information as outlined in Appendix 1 of this Audit Standard.

Site operating characteristics

Describe the nature of the site's business operation, and how each system audited relates to the site's operation. Identify and describe any future plant changes that will likely change the site's operating characteristics or have an effect on the systems audited.

Objectives and scope of the audit

Describe the following:

- The objectives of the base level audit, the systems included in the scope and level of investigations that were performed.
- The systems that have been excluded from the scope, the reason for them being excluded, and an estimate of their capacity and annual energy use.
- A description of what methods were used to assess the operation and performance of the systems.

Note: Where there is more than one independent refrigeration system on a site, Sections B and C should be repeated for each system.

B. Tariff Review

Include a tariff review for electricity, and also for the heating fuel used at the site if any heat recovery EMOs are identified during the audit. The tariff review for electricity needs to describe:

- The type of electricity contract used at the site (e.g. FPVV, TOU, Hedged or Spot).
- Tabulated costs of the variable and fixed charges associated with the electricity supplied to the site.

If the client is Time of Use, then a table of charges for each billed period across 12 months is useful for identifying periods of high and low cost.

When calculating the electricity savings for EMOs, only the variable portion of the electricity costs must be used.

C. System Overview

Describe the refrigeration system in the context of the site's operation, in terms that the client will recognise. Include the following:

- What the business driver is for the system (e.g. production output or material input).
- The current annual volume of that driver.

From this calculate the energy intensity of the system (kWh per unit of throughput/business driver).

Summarise the energy use of equipment within the refrigeration system, in tabular form. The data collected during the audit – using the tables in Appendix 3 and checklists in Appendix 4 – will provide the foundation for the analysis of energy consumed by the system.

This information should also be presented as pie charts to illustrate the annual energy consumption split for the refrigeration system. These charts should show the energy split by end use (i.e. the equipment that is using the electricity) and the energy split by location (i.e. the location of the equipment at the site).

D. Audit Findings

Overall findings

Describe the overall efficiency of the system and briefly outline the opportunities that will be discussed in more detail in subsequent sections. Appendix 3 provides the foundation for the energy management opportunities identified at the site during the energy audit.

If applicable, refer to system layout schematics in the appendices.

The energy opportunities should be segregated into sections for system demand, system network and system supply opportunities. For each opportunity in each section, describe the initiative in detail. Include estimations of energy use savings, energy cost savings, the implementation cost of the initiative, and the estimated project payback period. State assumptions made in the estimates and calculations, but there is no need to show calculation details unless it is important to illustrate the methodology used.

Each EMO should be concluded with a table showing the energy savings, cost savings and payback for the proposed opportunity. For example:

Electricity Savings		Fuel Savings		Total Savings	Cost	Payback
25,000 kWh	$ 2,800	0 kWh	$ -	$ 2,800	$ 4,000	1.4 years

System demand opportunities

Outline the aspects of the demand side of the system that have opportunity for improving the energy intensity of the system. Also refer to the relevant base level system checklist in the appendices.

Demand EMO 1

Demand EMO 2 ... etc.

System network opportunities

Outline the aspects of the system network that provide opportunities for improvement. Also refer to the relevant base level system checklist in the appendices.

Network EMO 1

Network EMO 2 ...etc.

System supply opportunities

Outline the aspects of the supply side of the system that provide opportunities for improvement. Also refer to the relevant base level system checklist in the appendices.

Supply EMO 1

Supply EMO 2 ...etc.