
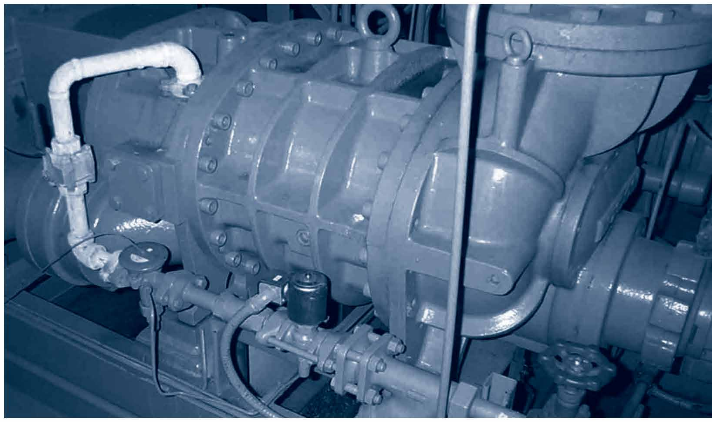
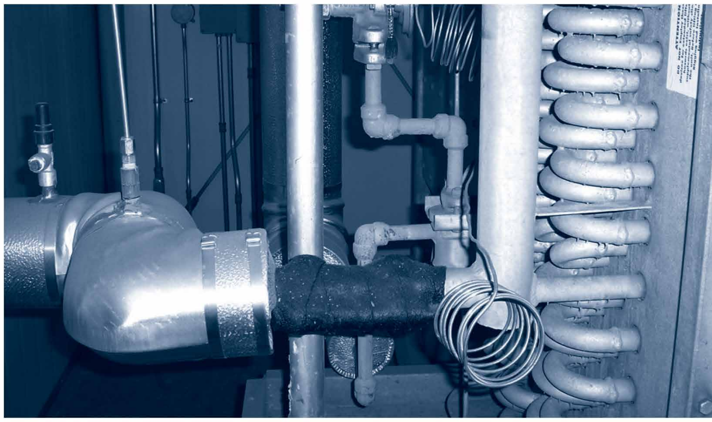

Industrial Refrigeration

BEST PRACTICES GUIDE

Cascade Energy

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CHAPTER 1

Introduction

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Background

This Guide identifies and discusses best practices for making industrial refrigeration systems both energy-efficient and productive. The highest levels of efficiency in these systems are achieved through a combination of design, construction, commissioning, operation, and maintenance coupled with a robust energy management program. This Guide provides insights into approaches to industrial refrigeration systems that cost less to operate, are reliable, can maintain accurate and consistent temperatures in refrigerated spaces, help ensure that processing equipment operates consistently, and can meet varying production needs.

This guide targets the full range of interested, influential, or affected parties associated with industrial refrigeration. This includes system operators, maintenance staff, design engineers, refrigeration contractors, equipment vendors, production staff, management, and owners. After reading this guide, it should be possible for anyone in this list to have a substantive and productive discussion about improving the performance of refrigeration systems. This guide contains a minimum of formulas, thermodynamic diagrams, and technical detail—just enough to achieve a common understanding and appreciation that enables real continuous improvement. The focus is real-world situations and solutions, not academic pursuit.

Goals

Ultimately, improving energy efficiency in industrial refrigeration is achieved by changing the business practices of food-processing companies, cold-storage and refrigerated warehouses, and the trade allies that support and serve them. Design standards and operation-and-maintenance practices that increase and maintain energy efficiency can also be adopted by users of industrial refrigeration and their engineering consultants and contractors.

In this context, the goals of this Best Practices Guide are:

- **To identify opportunities to increase electrical energy efficiency in industrial refrigeration systems** The Guide specifically focuses on energy savings measured in kilowatt-hours (kWh). It is written primarily for audiences where energy costs are the largest portion (usually over 80%) of typical electric bills. The Guide does not specifically address reducing peak monthly power demand, measured in kilowatts (kW). However, in most cases, a system that saves energy will also reduce peak demand. This Guide also does not address load-shifting strategies, where refrigeration load is shifted from a high-cost time period to a low-cost time period, nor does it address reactive power (power factor, or kVAR) or power-quality issues such as harmonics.

- **To better understand industrial refrigeration as a system** Energy efficiency in industrial refrigeration includes both selecting efficient components and integrating those components into an efficient system. The goal is to minimize the energy consumption of the entire system. Frequently, one or more small constraints in a system can limit the efficiency of the overall system. In other instances, reducing the energy use of one type of component may increase the energy use of another. Understanding the way the system behaves as a whole lets us avoid building in "weak links" and allows us to strike an efficient balance between components.
- **To motivate system designers, contractors, plant engineers, and owners to consider life-cycle costs when installing or upgrading industrial refrigeration systems** The equipment-supply and design-build businesses are very cost-competitive, and facility owners have limited capital budgets. Therefore, system design often emphasizes low initial cost rather than low life-cycle cost. Energy costs are the most significant ongoing life-cycle cost, and are a major component of the total present-value cost of a refrigeration system.
- **To highlight non-energy benefits of energy-efficient practices** In most situations, investments in energy efficiency can also reduce labor costs, increase productivity, increase product quality, and increase system reliability.
- **To emphasize that best practices include more than just system design** Commissioning and well considered operation-and-maintenance practices contribute importantly to the long-term energy performance of the system.
- **Encourage facilities to implement a robust energy management program** A successful energy management program allows a facility to sustain and improve upon the efficiency benefits that have been achieved. Key elements of a successful energy management program include establishing an "Energy Champion" that is accountable for system energy use, tracking Key Performance Indicators (KPIs) of system efficiency, ensuring that key personnel receive appropriate training, and creating a culture that embraces a continuous improvement philosophy towards energy efficiency.

Focus on Industrial Refrigeration

This Guide focuses solely on industrial refrigeration systems, which we define in the following broad terms.

Table 1: Qualifying attributes of industrial refrigeration systems

Attribute	Criteria
Size:	100 tons or larger
Refrigerant:	Ammonia (R-717) in the vast majority of cases, with some R-22 applications
System Type:	Centralized and built-up, as opposed to commercial refrigeration equipment, which is simpler, more modular, and distributed
Load Temperatures:	-60°F to 55°F with normally at least one load below 40°F
Function:	Primarily storage and processing of food products
Industries:	■ Refrigerated warehouses, including controlled atmosphere ■ Fruit and vegetable processors, ranging from fresh product storage to highly processed pre-prepared meals ■ Breweries and wineries ■ Dairy and ice cream processors ■ Meat, poultry, and fish processors

CHAPTER 2

Best Practices Overview

The Scope of Refrigeration Best Practices

This chapter addresses best practices for energy efficiency from a management level. We introduce four interrelated concepts that contribute to good business decisions. Best practices should encompass design, operation, maintenance, and commissioning. Attention to all of these activities will optimize overall system performance.

Design

- Designing the facility to reduce loads
- Selecting energy-efficient equipment and controls
- Integrating that equipment into a system that is optimized for efficiency at both peak and typical loads

Operation

- Trained and certified operators with a conceptual knowledge of energy-efficient practices and an understanding of refrigeration cycles
- Scheduled or regular review and documentation of key set points and operational strategies required for energy-efficient operation
- Using a control system to review operations to confirm efficient operation and to automate complex control strategies
- Observing equipment and gauge readings to confirm efficient operation

Maintenance

- Trained and certified maintenance staff and contractors
- Preventive maintenance practices
- Routine calibration of sensors, controls, and actuators that indicate system performance
- Routine cleaning and maintenance of evaporators, condensers and heat exchangers

Commissioning

- Implementing commissioning for new construction, for major retrofits, or periodically for all systems to ensure that the system, equipment, and controls meet process and energy-efficiency objectives

Life-Cycle Costs

Best practices encompass much more than just energy performance. In the broadest sense, best practices could be defined as follows:

> Design, operational, and maintenance practices that help minimize life-cycle costs to the system owner are based upon factors that include:

- Initial capital investment
  - The expected life of the equipment
  - The reliability of the equipment
  - The system operating costs, including energy, maintenance, and labor
  - The costs associated with product quality

- Capital and discount rate for the owner

Ideally, all of these costs and their interactions would be well understood, and selecting the "best practices" for a given situation would be straightforward. Real situations, however, are more complicated and have more unknowns, but we contend that in most cases, a system that is designed, operated, and maintained in an energy-efficient manner will typically have low life-cycle costs.

There is no single set of best practices that is ideal for every situation. We do not suggest that every conceivable energy-efficient option should be integrated into every system. The optimum design for a system that operates continuously at a relatively high load will be different than the design for a system with a short season with highly variable loads. Instead, we believe that it is warranted to consider a range of energy-efficiency choices when designing a new refrigeration system or modifying an existing system. Existing system constraints, energy rates, and utility or government incentives can all significantly influence which best practices are economically viable for a specific system.

Energy Efficiency—"The Big Picture"

Strategies for increasing the energy efficiency of industrial refrigeration systems fall into seven major categories:

- **Reducing System Lift**

  Refrigeration system "lift" is the difference between suction pressure and discharge pressure. Reducing lift by raising suction or lowering discharge pressure increases compressor efficiency.

- **Improving Part-Load Performance**

  In most systems, evaporators, compressors, and condensers often operate at less than their full capacity. There are many ways to control capacity, some more efficient than others.

- **Upgrading Equipment**

  Refrigeration equipment—from motors to condensers—can be upgraded or replaced with efficient design and configuration in mind.

- **Improving System Design**

  Designing a refrigeration system to address such issues as multistage compression, liquid subcooling, defrost configuration, and heat recovery can increase energy efficiency.

- **Reducing Refrigeration Loads**

  There are many ways to reduce the load that the refrigeration system must meet. Envelope upgrades such as increasing insulation, selecting better doors, and installing an efficient lighting system all reduce the amount of heat within the refrigerated space that the refrigeration system must remove.

- **Commissioning**

  Commissioning is the inspection, review, and adjustment of set points, control strategies, and equipment features, so as to achieve the design intent and meet original specifications, in a way that maximizes performance and efficiency. It ensures that you get what you pay for in your refrigeration system.

- **Operation and Maintenance (O&M)**

  O&M can be defined as maintaining originally specified equipment performance through proper service at specified intervals, and with the proper application of system-operation set points for optimal efficiency.

How to Implement Best Practices

Fully optimizing refrigeration energy use and thus controlling operating costs requires thoughtful planning. The checklist below includes steps that we have found helpful in maximizing system performance.

CHAPTER 3

Refrigeration System Basics

Introduction

In this chapter, we explain the basic vapor refrigeration cycle and describe the equipment typically used in industrial refrigeration systems. We discuss the various features and characteristics of this energy-using equipment and review system-control and variable-frequency drive (VFD) technology.

If you are already familiar with industrial refrigeration, this chapter can serve as a refresher or as background reference information. If you are unfamiliar with refrigeration, this chapter will introduce and explain critical basic concepts and terms that underlie best practices for energy efficiency. In any case, this chapter can serve as the basis of a common understanding of industrial refrigeration among the parties of various duties, responsibilities, and expertise—managers, maintenance staff, system operators, vendors, contractors, and so on.

Purpose of Refrigeration

The purpose of refrigeration is to remove heat from some medium—a fluid or solid—and transfer or reject that heat elsewhere. In most systems, heat is removed from the air (for example, a refrigerated warehouse), water or glycol (for example, a water chiller), or a food product (for example, ice cream), and transferred outdoors to the ambient environment. Although industrial refrigeration is also used in the chemical industry and in unique applications such as cooling the concrete during dam construction, the fundamental purpose and operation is the same.

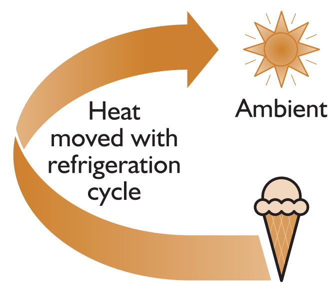

Figure 1: Refrigeration transfers heat from a medium to the ambient environment

Refrigerants

A refrigerant is a chemical compound that undergoes a phase change from liquid to gas and back as part of the refrigeration cycle.

Refrigerant selection is a complicated topic that goes beyond the scope of this guide. Three refrigerants are noteworthy for industrial refrigeration.

For food processing and storage, ammonia is the most efficient refrigerant.

- **Ammonia (R-717)** is by far the most common refrigerant in industrial refrigeration systems. It is inexpensive, energy-efficient, and does not deplete ozone.
- **R-22** (also known as Hydrochlorofluorocarbon-22 or HCFC-22) is the next most common choice. It is occasionally used in industrial refrigerant systems and is used commonly in smaller packaged refrigeration system. R-22 is slated for gradual phase-out in the United States under an international treaty called the Montreal Protocol due to its ozone-depletion potential.
- **Carbon dioxide** (CO_2) has been used in a few low-temperature hybrid refrigeration systems in recent years. These systems use CO_2 as the low-temperature refrigerant in conjunction with ammonia on the high-temperature side of the system in a cascade configuration.

All of these refrigerants work in the same general way. When a liquid refrigerant is heated (absorbs heat), it boils and turns into gas. When a gas refrigerant (vapor) is cooled, it condenses into a liquid and releases heat. The engineering terms for these processes are "evaporation" and "condensation." A refrigerant evaporating is no more complex a process than water boiling on a stove. Where water boils at 212°F at atmospheric pressure, ammonia boils at -28°F.

Many more issues and refrigerant traits affect the refrigeration cycle. Though there is certainly value in understanding the constant pressure-temperature relationship of a refrigerant—and issues such as enthalpy, entropy, and latent heat—for now, understanding that a refrigerant boils and condenses, absorbing and releasing heat in the process, is sufficient for a basic understanding of the refrigeration cycle.

Refrigerant Phases

Some terms are useful in describing what happens with refrigerants during the refrigeration cycle. Generally, substances exist as liquids, gases, or solids. These states of a substance are referred to as phases. To change from one phase to another, a substance has to absorb or reject heat. A good example of phase change is water. When water boils on the stove, the water (liquid) changes to steam (vapor). When it freezes, it changes to ice (solid).

Changing from a liquid to a gas is called evaporating, boiling, flashing, or vaporizing. The temperature at which a liquid evaporates varies with the pressure; as the pressure increases, the temperature at which it evaporates also increases. To evaporate, the liquid must absorb or gain heat from its environment.

Changing from a gas to a liquid is called condensing. When a liquid condenses, it gives off or rejects heat to the environment. Like evaporation, the condensing temperature varies with the pressure. At high pressures, the condensing temperature is high.

The heat required for a phase change is called the latent heat. Changing phases takes much more heat than changing the temperature of a gas or a liquid. For example, condensing one pound of ammonia vapor at 85°F gives off almost 70 times more heat than is given off cooling one pound of ammonia vapor from 100°F to 85°F. Likewise, evaporating ammonia at 0°F takes over 100 times more energy or heat than warming the same amount of liquid ammonia from -5° to 0°F.

Three additional terms commonly used are superheat, sub-cooling, and saturated vapor. Superheat refers to additional heat added to a gas, increasing its temperature. Before a gas will begin to condense to liquid, all of the superheat must be removed. Sub-cooling is when liquid is cooled below the boiling point. Heat must be added to a sub-cooled liquid before it will begin to boil or evaporate. Saturated vapor exists at the temperature and pressure where both liquid and gas can be present. Adding heat will change part of the liquid to gas without changing its temperature. If heat is lost, some gas will change to liquid without changing temperature. Any vessel with both liquid and gas is at the saturation point.

Refrigeration systems adjust the pressure of the refrigerant to control the evaporating and condensing temperatures of the refrigerant. By doing so they can remove heat from the area or substance to be cooled and reject the heat to the environment.

Air Dry-Bulb and Wet-Bulb Temperatures

In industrial refrigeration, we typically refer to air temperature with the terms dry-bulb or wet-bulb. Simply put, the dry-bulb temperature is the traditional measurement that can be made by a thermometer or temperature sensor. Dry-bulb is often used when calculating refrigeration loads. Dry-bulb does not consider humidity or other properties of the air.

Web-bulb is a bit more nuanced. Although air temperature is important, we are also very interested in how much moisture is in the air. The wet-bulb temperature is a measurement that reflects both of these properties. If you wet your finger and held it up in the wind, the water on your finger would cool due to evaporation. The lowest temperature your finger would feel would essentially be the wet-bulb temperature. Wet-bulb is required when assessing evaporative condenser performance and refrigeration loads caused by warm air entering refrigerated spaces (e.g., docks, coolers, or freezers). We will refer to wet-bulb later in this guide.

CHAPTER 4

Best Practices for Equipment, Systems, and Controls

Introduction

This chapter covers engineering opportunities to improve refrigeration system design, select efficient components, and control the system optimally. The chapter methodically addresses the "Big Picture" efficiency categories introduced in ***Chapter 2: Best Practices Overview***:

- Reducing Lift (below)
- Improving Part-Load Performance (page 58)
- Upgrading Equipment (page 68)
- Improving System Design (page 74)
- Reducing Refrigeration Loads (page 81)

At the end of this chapter, we highlight the importance of computer controls (page 84) and provide three checklists (page 85) pertaining to evaporators, compressors, and condensers that help tie together these concepts.

Reducing Lift

Introduction

"Lift" in a refrigeration system is the difference between suction pressure and discharge pressure at the compressor. Reducing lift by raising suction pressure or lowering discharge pressure improves compressor efficiency. Three general rules apply to lift:

- Increasing suction pressure increases compressor capacity.
- Reducing discharge pressure decreases power.
- Increasing suction or reducing discharge pressure reduces BHP/TR (brake horsepower per ton refrigeration) and thereby increases efficiency.

This section presents methods for reducing lift, discusses some of the barriers to doing so, and presents the potential energy savings. Note that suction and discharge pressure are often referred to as temperatures, as there is a direct, proportional and consistent relationship between the pressure and temperature of saturated ammonia vapor. This section will sometimes use one or the other description. Table 7 describes the relationship between pressure and temperature for ammonia.

Increasing Suction Pressure

Effect of Increasing Suction

The efficiency of a compressor in an industrial ammonia refrigeration system increases by about 2% per degree Fahrenheit increase in suction temperature. Although the efficiency improvement depends on actual operating pressures, compressor design, and refrigerant, the relationship of pressure change and savings is relatively consistent.

Table 7: Relationship between pressure and temperature for ammonia at sea level

Pressure	Temperature	Pressure	Temperature
-15 in. Hg	-51.4 °F	50 psig	33.8 °F
-10 in. Hg	-42.1 °F	60 psig	41.0 °F
-5 in. Hg	-34.5 °F	70 psig	47.3 °F
0 psig	-27.9 °F	80 psig	53.2 °F
5 psig	-17.3 °F	90 psig	58.5 °F
10 psig	-8.5 °F	100 psig	63.5 °F
15 psig	-1.0 °F	120 psig	72.6 °F
20 psig	5.6 °F	140 psig	80.7 °F
25 psig	11.3 °F	160 psig	87.9 °F
30 psig	16.6 °F	180 psig	94.7 °F
40 psig	25.8 °F	200 psig	100.8 °F

Energy savings from increased suction are seen at the compressor. When you increase the capacity of the compressor, it will operate at a lower fraction of its full-load capacity when meeting a given cooling load. Hence, the part-load performance characteristics of the compressor ultimately dictate the magnitude of the energy savings. In the same way, an increase in suction may actually allow a compressor to be turned off, or a large compressor to be shut down in favor of a smaller one. So although the 2% rule of thumb is good for estimating, a complete analysis of compressor operation would be needed to determine savings precisely.

Generally, the best opportunities for saving energy by increasing suction pressure are seen at low pressures. Freezer suctions are often excellent candidates. To increase the suction pressure, you may need to address barriers such as excessive pressure drop in the suction piping, poorly calibrated pressure transducers, or inefficient compressor control.

Regulating Suction Pressure

Suction pressure is maintained by compressor set points. Regulating suction can be as simple as adjusting the set point in a computer-control system. With other control systems, you may need to adjust a micro-processor panel on a screw compressor or a pressure switch on a reciprocating compressor.

Best Practices: Suction Pressure

- Suction pressure should be held where compressor power and evaporator fan power are at a "combined minimum."
- When no fan savings are possible, set suction pressure as high as possible.
- A small increase in suction pressure will often let the operator shut off a compressor. This strategy should be pursued aggressively—particularly for systems with screw compressors.

Selecting Larger Evaporator Coils

The cooling capacity of an evaporator is directly proportional to the difference between the temperature of the air entering the coil and the temperature of the refrigerant within the coil. This difference in temperature is called the temperature difference, or TD. Evaporator coil capacity is also proportional to the area of the heat-exchange surface of the coil. So by using a larger evaporator coil (one with more surface area), you can reduce the TD and still maintain cooling capacity. This lets you increase suction pressure while providing the same amount of cooling in the space.

Typically, evaporator coils are selected based on their capacity at a TD of 12 to 15°F. By using a larger coil that allows a TD of 10°F or even 8°F you can increase suction temperature. For example, reducing coil TD from 15°F to 10°F will allow a 5°F increase in suction temperature and reduce compressor energy consumption about 10%:

$$(15°F – 10°F) \times 2\%/°F = 10\% \text{ savings}$$

CHAPTER 5

Best Practices for O&M and Commissioning

Introduction

This chapter discusses best practices for achieving energy efficiency through the operation, maintenance, and commissioning of refrigeration systems.

Operation and maintenance (O&M) can be defined as maintaining originally specified equipment performance through proper service at the specified intervals. Even the most efficient system design and equipment can be rendered inefficient by inadequate O&M. It is important that proper O&M practices be followed throughout the life of the system.

Commissioning can be defined as the inspection, review, and adjustment of set points, control strategies, and equipment features, to ensure that the system achieves the design intent and meets original specifications in a way that maximizes performance and efficiency. Systems should be commissioned when they are built (or modified) and should be periodically recommissioned.

Operation and Maintenance

Introduction

Without proper O&M there is a natural degradation in equipment capacity that will occur due to dirt build-up, scaling, equipment wear, and drift or error in sensors or controls.

On a high level, best practices for O&M involves:

Practicing Preventive Equipment Maintenance Normally maintenance is equated with the reliability and longevity of equipment. Energy performance is another factor. Without exception, equipment that is in poor mechanical condition is less efficient than well-maintained equipment. In addition, leaky valves and other low profile elements of the system that are not addressed can have a serious negative effect on system performance.

Maintaining Evaporators and Condensers for Peak Performance These heat exchangers must be cleaned. Metal conducts heat readily. Dirt, oil, and scale are impediments to effective heat transfer. Eliminating non-condensable gas and assuring good condenser spray water coverage across the condenser surface area are two related concepts that contribute to peak performance. When evaporator or condenser performance is reduced, it can affect the system detrimentally as follows:

- Force the system to operate at less efficient operating pressures.
- Force fans or pumps to operate more frequently (or at a higher speed).
- Sacrifice space or process temperatures.
- Reduce system capacity.

Performing Periodic Calibration Calibration is primarily associated with maintaining process or space temperatures at targeted levels. However, instrumentation and controls that are out of calibration can negatively affect energy performance. Poorly calibrated pressure gauges, temperature sensors, and slide valves can lead to:

- Overly conservative settings that compensate for the unknown.
- Faulty interpretation of problems with the system.

- Less effective control algorithm performance.

Tracking Equipment and System Performance Best practices include establishing habits and procedures that allow the emerging problems to be identified and fixed before they affect process or energy performance. This includes maintaining daily engine room logs, trend-logging control points with a computer-control system, and comparing performance over time.

Seeking Optimization The operators that attain the highest levels of efficiency make regular adjustments to control system settings and adjustments to equipment. These adjustments are followed by observation or measurement to see how the system responds.

Being Well-trained Knowledgeable maintenance staff and operators have a better understanding of all of the items on this list. They also have a better conceptual understanding of the overall performance goals. Plus, training often is used to satisfy PSM requirements as per federally mandated OSHA standards.

The following sections address some key O&M issues for evaporators, compressors, and condensers that affect energy performance.

Evaporators

Clean Coils Clean evaporator coils regularly. Pressure washing can remove dirt that accumulates on evaporator fins and tubes. This is especially true in dirty or dusty environments.

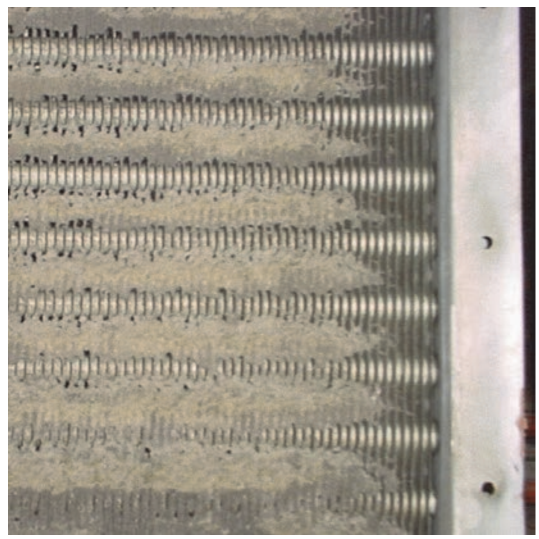

Figure 75: Dirty evaporator coil

Fix Leaking Valves Rebuild liquid and gas valves when leaking or other improper operation is detected. For example, a leaking hot-gas defrost valve will impart false refrigeration loads by leaking gas into the suction line.

Properly Adjust Hand Expansion Valves The liquid feed valve must be properly adjusted or the coil will not be able to operate at the rated capacity. If the valve is closed too much, the coil will "starve". If the valve is open too much, "brining" will occur (where the liquid is rushing through the coil) too fast for optimal heat transfer. The hot-gas defrost hand expansion valve settings can affect the efficiency of the defrost cycle.

Calibrate Temperature Probes and Sensors
Calibrate temperature probes and sensors regularly using a consistent and traceable standard (for example, an ice bath).

Replace Failed Motors or Controls Failed evaporator motors lessen total coil airflow (cfm) and capacity. The failed motor also creates an alternate path for air to flow back through the fan shroud on the front of the evaporator . This includes failed fuses, contactors, overloads, and VFD faults.

Check Air Temperature Drop Track or check air temperature drop across the evaporator coils. This technique helps identify evaporators that are underperforming. Underperforming coils should be debugged to identify and address the underlying problem. For example, a typical evaporator coil in a freezer application should provide approximately ½ degree reduction in air temperature per degree temperature difference (entering air minus refrigerant temperature).

Compressors

Calibrate Slide Valves on Rotary Screw Compressors Rotary or linear potentiometers are often used to measure slide valve position (and for variable VI, the slide stop position) on a screw compressor (Figure 76). The potentiometers eventually drift or wear, preventing the compressor from properly

CHAPTER 6

Tools for Implementing Best Practices and Energy Management

Introduction

This chapter explains the benefit of incorporating a robust energy management strategy and provides a variety of resources and approaches that can help you understand and control your refrigeration system energy costs. An effective refrigeration energy management strategy strives to raise awareness of energy use and operating costs. All plant staff should have full knowledge of the costs of running the refrigeration system—from plant engineers, process operators, to maintenance staff. Owners and plant management also need to see energy costs as a variable rather than a fixed expense. If both operators and management are aware of the energy use, the related energy costs, and the options available to control them, the team is more likely to select efficient choices that minimize life-cycle cost and maximize profits.

This section includes the following:

- Examples of energy management strategies used at industrial facilities and key elements of successful programs.
- An overview of Key Performance Indicators (KPIs) that can be employed on an industrial refrigeration system to measure system performance and ensure that efficiency improvements are sustained and improved over time.
- A self-assessment questionnaire that allows you to consider how all aspects of your refrigeration system can influence operating costs. This includes equipment choices, control methods, system design, operation and maintenance, and management techniques.
- An overview of life-cycle cost analysis.
- An example of how to estimate the annual energy cost of your refrigeration system.
- An overview of the techniques and benefits of refrigeration energy-efficiency studies.
- A discussion of energy-accounting practices and their benefits.
- A reference section that includes a variety of sources for information on industrial refrigeration engineering and operation.

Why Improve How You Manage Energy?

Companies manage energy for the same reasons they manage labor, safety and raw materials: to improve profitability by controlling and reducing costs. This guide has presented several opportunities to reduce energy use in refrigeration systems ranging from capital projects to improved O&M practices. The return on implementing these opportunities will be dependent on the strength of the company's energy management program. Ask yourself, how can you expect to sustain and improve energy performance if you do not have designated leadership, clear goals, accountability, and measurable results, and have not instilled a continuous improvement philosophy?

How can you expect to sustain and improve energy performance if you do not have designated leadership, clear goals, accountability, and measurable results, and have not instilled a continuous improvement philosophy?

Increasingly, companies are realizing the benefit of a robust energy management program. For some, sharp increases in energy costs have led them to make this change. For others, past cost reduction initiatives such as Lean Manufacturing have been pursued to the full extent. Energy represents the next layer of opportunity to reduce costs. The bottom line is that increased global demand for energy, tightening environmental regulations, and growing threats such as global warming will undoubtedly increase the cost and availability of energy in the future. Those companies with an effective energy management program that have reduced energy costs and reinvested savings in new energy projects will have a considerable competitive advantage.

Industrial Energy Management Strategies

A wide range of energy management strategies are employed at industrial facilities. For many, there may be no formal energy management program. The monthly electric and gas utility bills are simply paid and filed away. For others at the other end of the extreme, energy is an integral consideration in all aspects of business decision-making. The strategies employed by companies generally fall into one of five categories:

1. **Do Nothing** Simply pay the utility bills. For some, energy may be perceived as a fixed cost that cannot be affected. For others, the resources required to reduce energy costs is believed to outweigh the potential benefit.
2. **Price Management** Seek ways to reduce the cost of energy such as fuel switching or finding lower energy supply costs. Some facilities may view energy costs as the only variable that can be controlled. For others, reducing the cost of energy is simpler than upgrading equipment or trying to change plant culture.
3. **Low-Cost, No-Cost Opportunities** Try to do the best you can with what you have. Management may set goals to "Reduce energy use by 10% without spending any money". One-time efforts to tune equipment and operating strategies can produce significant energy savings immediately. While this is a good starting point towards assessing energy management opportunities and finding an immediate "success," these savings often erode over time if adequate procedures, measurements, and roles are not created to sustain success.
4. **Capital Projects** Pursue equipment upgrades that improve efficiency. This is pursued by facilities that feel that efficiency is primarily an equipment issue or want to avoid tackling efficiency from a staff perspective. Energy cost savings can be significant but fall short of true optimization because of the failure to address opportunities from the human perspective.
5. **Strategic Energy Management** Incorporate energy into all aspects of normal business operations. A facility develops a formal energy policy, assigns leadership and sets goals. An energy plan enables a facility to prioritize opportunities and assign roles and responsibilities for achieving goals; the next step is to pursue capital projects and low-cost, no-costs methods to reduce energy use. By tracking Key Performance Indicators (KPIs), a facility can measure system performance and improvements in energy productivity.

Clearly, a Strategic Energy Management program presents the best opportunity to fully optimize energy efficiency. An energy management program is most effective when it is appropriately scaled to meet the needs of a facility. In general, the greater energy costs are and the greater percentage of total operating costs energy represents, the greater opportunity for a comprehensive energy management program.

Elements of a Successful Energy Management Program

The fundamental elements of a successful energy management program are no different than you would find for other initiatives. Establishing goals, tracking results over time, designating leadership, and outlining roles and responsibilities, and education and training opportunities, are the fundamental building blocks of any successful management strategy, whether it is energy or safety. Not surprisingly, companies will often borrow from existing programs such as Six Sigma or Lean Manufacturing as the framework of their energy management program.

Full energy savings potential comes from a corporate commitment to strategic energy management in four key areas of organizational structure, people, manufacturing systems and measurement: The following are

System Assessment Questionnaire

This questionnaire covers most aspects of equipment and operations for industrial ammonia refrigeration systems found in a "typical" food processing facility. Relative weighting has been assigned to various questions as a rough approximation of their importance to overall efficiency and thus, their effect on operating costs. **Note:** The questions do not cover every possible efficiency scenario.

To assess the efficiency or efficiency potential of your refrigeration systems, you can compare the subtotals from each section of the questionnaire and also your total score to the table at the end. The first line in each section of the questionnaire refers you to relevant pages of the Best Practices Guide for more information. There's more information on interpreting your score at the end of the self-assessment.

Section 1: Suction Pressure

See ***Reducing Lift***, page 49.

1 The saturated suction temperature on your system is about how many degrees less than the lowest air temperature or liquid temperature served? The scores acknowledge that closer temperature approaches are practical for liquid loads than for air loads. Base your answer on the single lowest-temperature load in your system.

For air loads:	For liquid loads:	Points
20°F or more	10°F or more	0
15°F to 20°F	7.5°F to 10°F	1
12°F to 15°F	6°F to 7.5°F	2
10° to 12°F	5°F to 6°F	3
10°F or less	5°F or less	4

Score ☐

2 The controls for our system allow space temperatures to pull down below the required temperature by more than 2°F.

	Points
Yes	0
No	1

Score ☐

3 Which of the following descriptions best describes your system:

	Points
We maintain our suction pressure **below** its design suction level to be conservative and run all evaporator fans at full speed	0
We maintain our suction pressure **at** its design suction pressure and run all fan evaporator fans at full speed.	1
We allow our suction pressure to float **above** the design suction pressure while running all evaporator fans	2
We operate at the highest allowable suction pressure that still allows some fan cycling or fan-speed reduction	3

Score ☐

4 A small but colder load on our refrigeration system determines the suction pressure we run, while a larger load on the same system could handle a higher suction pressure. (An example is an ice cream room on the same suction as a main freezer.)

	Points
Yes	0
No	1

Score ☐

12 Which of the following best describes the typical unloading of our compressors?

Points

It is common to have two or more screw compressors operating at less than 100% capacity on the same suction system. 0

All operating compressors remain fully loaded, but operate at lower than necessary suction pressures. 2

Our control system fully loads our "base-load" compressors with one screw compressor acting as "trim" compressor by unloading the slide valve to maintain suction pressure at set point. 4

Our control system fully loads our "base-load" compressors with either a reciprocating compressor or VFD-driven screw compressor acting as the "trim" compressor. 6

Score

Points for Section 4: Compressor Control and Sequencing	14 points possible

Section Score

Section 5: Condenser Control and Sequencing

See ***Improving Condenser Part-Load Performance***, page 65.

13 Which of the following best describes our condenser sequencing?

Points

Our system cycles fans for condensing pressure control. Each condenser fan stage has a distinct "cycle on" set point and "cycle off" set point. The set points for successive stages are staggered such that all condenser fans are not on-line until the system pressure is above the minimum allowable discharge pressure. 0

Our system cycles fans for condensing pressure control. There is a single set point for all condenser fan stages. When the pressure climbs above the set point, another fan stage is brought on-line. 1

Our condenser fans are controlled with two-speed fans or VFDs. There is a single set point for all condenser fan stages. The system ramps one VFD to full speed, prior to bringing the next VFD-driven fan on-line. 2

Our condenser fans are controlled with two-speed fans or VFDs. There is a single set point for all condenser fan stages. We ramp all fans at the same speed. 3

Score

14 We operate our condenser fans first and our pumps second.

Points

Yes 0

No 2

Score

Estimating the Annual Energy Cost of Your Refrigeration System

One of the first steps toward assessing refrigeration energy efficiency in terms of life-cycle costs is determining how much energy your system uses per year and the resulting energy costs.

Calculating energy costs is very straightforward for facilities where the refrigeration system is by far the largest electrical load. This would occur, for example, in some refrigerated warehouses. In these cases, an analysis of electric utility billing history is all that's required.

For systems where refrigeration represents only a fraction of the total electrical consumption, estimating energy use is a little more challenging. Below is a sample calculation for a hypothetical refrigeration system. The calculation points out several suggested sources for data and suggests some analytical shortcuts. With reasonable data, you should be able to estimate energy use and cost within about +/- 15%.

It is more difficult to make these estimates while planning new construction. However, it is even *more important* to try to estimate annual energy costs in those situations. Planning and design provides by far the best opportunity for evaluating life-cycle costs, assessing efficiency potential and implementing measures found cost-effective in terms of energy and other benefits. Detailed energy studies (see ***Using an Energy Study as a Management Tool*** on page 114) involve more rigorous estimates of energy use and cost, and are an excellent idea when planning new construction or major renovation.

An energy estimate also helps explain which pieces of equipment in your system are the largest contributors to total energy use. In some systems (controlled atmosphere facilities for one), the large compressor motors are not the largest energy users (since energy use is the product of both horsepower and operating hours). This insight can help you concentrate your efforts on the equipment with the most potential and get the ***biggest effect for the least effort***.

Compressor Energy Estimate

Compressor Number	Motor nameplate (hp)	Motor Full Load Amps	Typical motor amps	Typical input power (kW)	Hours per year	Annual Energy (kWh)
1	300	330	250	182	7,000	1,272,727
2	300	330	275	200	4,000	800,000
3	200	220	180	131	3,000	392,727
4	200	220	175	127	2,000	254,545
5	200	220	180	131	2,000	261,818
Total						**2,981,818**

Motor Full Load Amps: From motor nameplate

Typical motor amps: Possible data sources would include manually recorded engine room logs, refrigeration control system history, or amp measurements at typical operations.

Hours per year: Engine room logs that include hour meter readings are an excellent source for estimating hours per year.

Annual Energy: kWh are simply kW x hours

Typical input power: Technically:
kW = motor shaft power x .746 / motor efficiency
but a decent approximation is:
kW = Motor Nameplate hp x typical motor amps / motor full load amps * 0.8