Energy Best Practices Guide | October 2020

DAIRY PROCESSING INDUSTRY

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DAIRY PROCESSING INDUSTRY ENERGY BEST PRACTICES GUIDEBOOK

FOCUS ON ENERGY®, Wisconsin utilities' statewide program for energy efficiency and renewable energy, helps eligible residents and businesses save energy and money while protecting the environment. Focus on Energy information, resources and financial incentives help to implement energy efficiency and renewable energy projects that otherwise would not be completed.

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Introduction

This guidebook is one in a series developed to highlight energy efficiency best practices in common sectors of the industrial market. The guidebook contains individual best practice descriptions and tips for overcoming common barriers encountered during implementation.

The information provided in the guidebook was identified and screened during site visits to industrial facilities in this market segment. This guidebook will be updated as new best practices are identified and screened for applicability. To suggest an energy-related best practice for inclusion in this guidebook, please contact Focus on Energy at 888.623.2146.

Are you a world-class industrial energy user?

World-class energy users have:

1. Received firm commitments from management for plant-wide improvements in energy efficiency and demand reduction
2. Aligned energy using equipment decisions with corporate goals
3. Baselined energy consumption in their plant
4. Benchmarked best practice opportunities
5. Defined a quantifiable, affordable energy reduction goal
6. Established a multi-year plan to meet energy reduction goals
7. Identified the necessary internal and external resources to meet goals and to provide feedback to continuously improve plan

If your plant lacks any of these essential ingredients, this guidebook will help you get there.

ENERGY MANAGEMENT BEST PRACTICES

Any organization can more effectively manage its energy use and costs by adopting a continual improvement approach to energy management, commonly known as an **energy management program** or **Strategic Energy Management (SEM)**. An energy management program provides a systematic and proactive approach to assessing and reducing the energy uses and costs of your organization.

An energy management program is not a single project but an ongoing process. It can be a stand-alone effort devoted exclusively to energy management or adapted to an existing management program such as existing quality assurance or environmental management programs at a facility. The most successful energy-management programs are developed and maintained by a team of individuals from various functions such as maintenance, engineering, production, financing and management.

Energy efficiency is a good investment. Typically, energy cost savings of as much as 15% can be achieved in three years by implementing a systematic energy-management program.

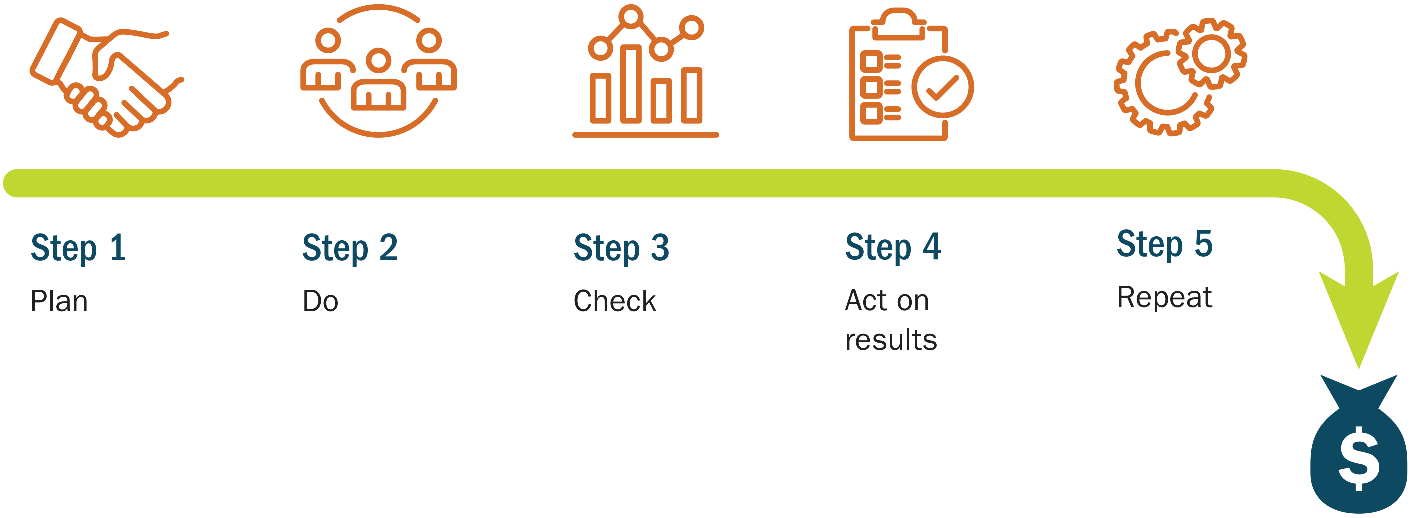
At first glance, creating and implementing an energy-management program may seem to be an overwhelming task, but it doesn't have to be. This chapter outlines simple steps following a Plan, Do, Check, Act continuous improvement cycle for putting the basic elements of energy management in place within your organization.

Steps to getting started

The next several pages outline the steps toward developing and implementing a continuous systematic energy management program. Focus on Energy can assist with completing any of these steps.

There are other well-established energy management protocols to consider including CEE's Strategic Energy Management Minimum Elements (www.cee1.org), the 50001 Ready program by the Department of Energy, or the ISO 50001 standard.

Basic steps in building an energy management program



Step 1
Plan

Step 2
Do

Step 3
Check

Step 4
Act on results

Step 5
Repeat

Step 1 — Plan

Obtain support from plant management

Start with discussing the need for better energy management with the decision makers at your facility. It is critical plant management support these efforts and are willing to allocate resources, both time and money, to achieve those goals and there is accountability for goal achievement.

It is helpful to prepare a business case for plant management. What is your total plant's annual energy spend? What is a reasonable/achievable reduction in annual energy costs because of better energy management? How much staff time can be justified by the estimated reasonable annual energy savings? Focus on Energy can help build this business case.

Establish your energy-performance baseline

Establishing a baseline is critical for goal setting and monitoring progress towards goal achievement. There are multiple ways to establish baseline energy consumption. The following list of possible baselines is in order of increasing effort but also increasing value.

Basic — Gross energy consumption

Using an average annual or monthly gross energy consumption is the easiest baseline to develop, but it is also the least useful. While this approach gives a rough baseline to track future performance against, it does not account for factors which may change your energy consumption based on business demands, like increased production, or reasons out of your control, like weather. This approach is most useful in a plant with stable energy-using processes not impacted by weather.

Better — Production energy intensity metric

By combining energy consumption and production data, you can build a baseline for energy intensity.

Building this baseline is done by dividing electricity consumption (kWh) and gas consumption (therms) by total production volume for the same time period. This can be tracked at any interval desired, such as daily or annually. See the second column in the example below.

Establishing baseline consumption

MONTH	KWH/UNIT	CONSUMPTION (KWH)	PROD UNITS	BILLED DEMAND (KW)	TOTAL ELECTRIC POWER COST
Jan	2.61	2,253,240	862,560	4,953	$103,650
Feb	2.51	2,123,070	845,040	4,953	$97,661
Mar	2.57	2,198,420	855,090	4,953	$101,127
Apr	2.49	2,056,720	826,640	4,953	$94,609
May	2.42	1,989,730	821,970	4,953	$91,528
Jun	2.49	2,106,030	844,490	4,797	$96,877
Jul	2.45	2,034,040	831,540	4,794	$93,566
Aug	2.50	2,102,320	840,200	4,728	$96,707
Sep	2.45	2,060,210	839,310	4,771	$94,770
Oct	2.41	1,983,040	821,180	4,771	$91,220
Nov	2.45	1,964,920	801,040	4,771	$90,386
Dec	2.45	1,988,640	810,940	4,771	$91,477
Avg Total	**2.49**	**24,860,390**	**10,000,000**	**4,847**	**$1,143,578**

Electric rate $0.046/kWh

This approach is better than tracking gross energy consumption but results in a wide range of values because it only takes into consideration one driver of energy consumption – total production. Most production facilities have other important drivers such as product mix, weather and operational mode, among others. This can impact the usefulness of this information and can negatively impact employee buy-in to supporting energy improvements.

Step 1 — Plan (continued)

Best — Multi-variable regression modeling

Multi-variable regression modeling is often the most accurate and useful method of creating a baseline. This approach uses a mathematical equation, taking into consideration multiple variables including but not limited to product lines, temperature, humidity, days of the week, mode of operation and plant shutdown time.

Example regression model equation

kWh/day = 45,000 + 67*(Cogs) + 74*(Wheels) + (1,500*Cooling Degree Days) – 26,000*(Weekend)

Once a model is established, it can be used to compare expected daily consumption against actual utility meter readings for each day. Differences between the model and actual energy consumption can be accumulated over time in a useful visual layout called a cumulative sum control chart. The value of this graph represents normalized savings to date, and the path of the graph over time can be useful in identifying unexpected energy performance impacts from operation adjustments.

Regression modeling can be done using any number of readily available tools such as Microsoft Excel or open-source statistical software. Effective regression modeling is best done by an experienced and trained statistical modeler. Contact Focus on Energy for assistance in developing a regression model.

Identify opportunities

Best practices are techniques or technologies recognized as being economical and more efficient than common practices. Review best practices in comparison to your equipment and system profiles to identify opportunities for energy efficiency improvements. Focus on Energy can assist you in identifying and prioritizing opportunities for your facility.

Quantify savings and costs of opportunities

Once opportunities are identified, the next step is to estimate the cost savings, including energy, maintenance and installation. Focus on Energy provides technical assistance for quantifying energy savings for projects as needed.

Prioritize projects

This step can be done with your energy team or upper management. Apply criteria such as return on investment, capital cost or ease of installation to help prioritize the projects identified. Select the highest-scoring projects for implementation to achieve your energy-saving goals within time and budget constraints.

Set a goal

Use the prioritized projects to inform a goal. What is achievable this year? The goal doesn't necessarily have to be an amount of saved energy; it could be to maintain current plant performance. Most sources agree intentional plant management can save between 1% - 5% of a plant's annual energy consumption depending on how much a facility has already invested in energy efficiency.

Form an energy team and establish meeting frequency

Effective energy management requires input from many levels of plant operations. The size of an energy team will depend on the magnitude of the annual energy spend. Plants with very large annual energy costs can justify a bigger energy team and more frequent meetings. Smaller plants may only be able to justify assigning the role of energy manager to a single staff person who reports to the general plant management team.

It helps to set a standard agenda to ensure meetings are efficient and effective. Typical energy team meeting agendas have at least two components:

1. Review progress on selected projects and initiatives.
2. Review and discuss performance to date against the baseline.

Step 2 — Do

Regular energy team meetings

The energy team should meet according to the frequency set forth in the planning phase and discuss progress and challenges for the projects identified.

Project management and implementation

Manage each energy project selected for implementation by clearly defining project parameters, assigning responsibilities for project implementation, setting deadlines and undertaking specific tasks needed to implement the project. Progress on projects should be reported during energy team meetings.

Step 3 — Check

Monitoring progress against baseline

At each meeting, the energy team should report on progress against the selected baseline. For a gross energy consumption baseline, how much energy has been consumed to-date and how does it compare to this time last year? For energy-intensity baseline, what was the energy consumed per unit of production last month and how does this compare to the baseline metric? And for regression-based baseline models, over the past month, did the plant consume more energy than the model expected? The team should discuss causes to explain results. Did any implemented projects result in the expected savings?

Figure 1: KPI goal and tracking

This graph depicts Key Performance Indicator (KPI) tracking of a simple energy intensity KPI.

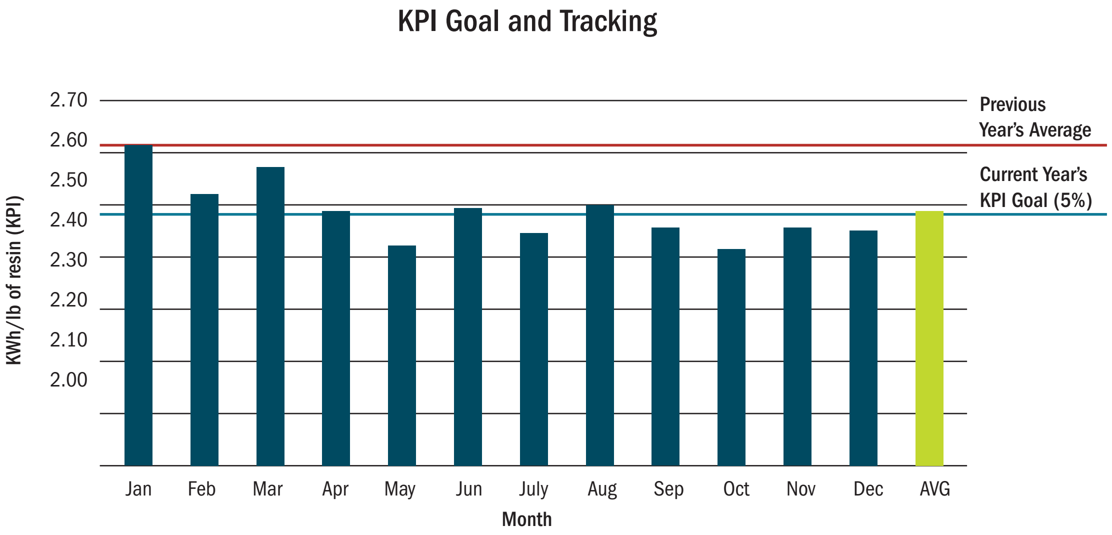
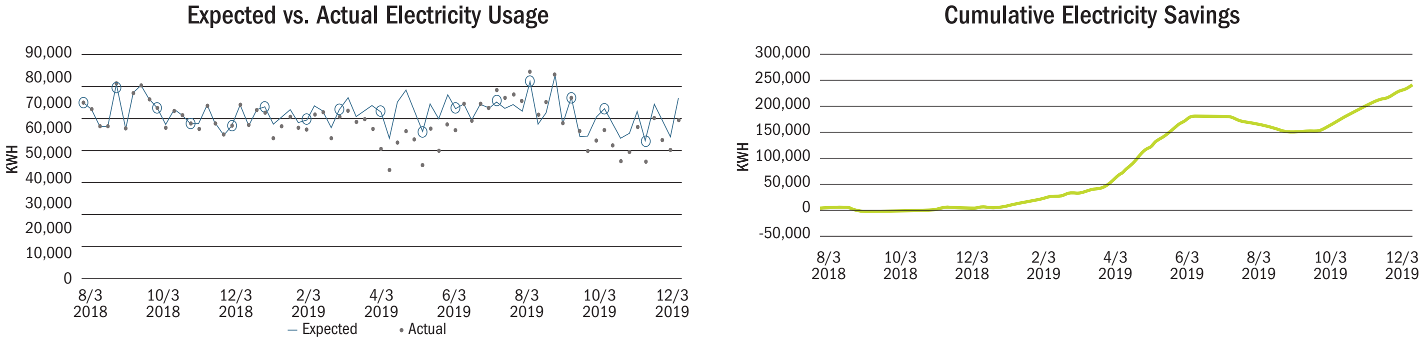


Figure 2: Tracking energy performance

This graph depicts tracking energy performance using a regression model approach.



Reports to management

The energy team should report to upper management at regular intervals. This can include reviewing projects completed, sharing results found using a baseline comparison and discussing progress towards goals.

Step 4 – Act

Acting on results

One of the primary benefits of an established energy management program is the opportunity for continuous improvement. Continuous improvement involves constantly adjusting tactics and strategies based on actionable data. Each energy team meeting and report to management is an opportunity to recognize a need to act. If the energy performance of the plant is degrading, determine why and what needs to be done. If the expected savings from a project are not being realized, assign a task to find out why. If an established goal is deemed too aggressive, reduce the goal and document lessons learned. Each cycle of continuous improvement will result in lessons learned and can be applied to the planning phase of the next cycle.

Step 5 – Repeat

Repeat the four steps above on a regular basis. Most plants revisit the planning phase at least annually during other regular annual planning cycles.

TECHNICAL BEST PRACTICES

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Refrigeration

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General

R1 – Reset floating head pressure control

Best practice	Many refrigeration systems operate with unnecessarily high head pressure. Lowering your system's minimum head pressure setpoint can result in significant energy savings.
Primary area/process	Industrial refrigeration systems.
Productivity impact	None as long as product design conditions are met.
Economic benefit	This practice involves resetting controls at no capital cost. Payback is immediate. Equipment or system changes may be required (see Applications and limitations below).
Energy savings	Refrigeration-system efficiency improvements range between 5% - 20%.
Applications and limitations	There are limits on how much a system's minimum head pressure can be lowered. Most constraints come from the decreased pressure of high-pressure liquid being fed to the low side of the system and include pressure differential requirements for direct-expansion loads, liquid injection oil cooling for screw compressors, hand-expansion valve settings for liquid makeup to recirculators and flooded evaporators, controlled-pressure liquid-receiver setpoints, and operation of gas-driven transfer systems. Each of these must be evaluated for a system.
Practical notes	Most industrial ammonia refrigeration systems operate with a minimum head pressure setpoint in the range of 150 - 165 pounds per square inch, gauge (psig). Lowering the minimum head-pressure setpoint is the single largest energy efficiency opportunity for most plants. The compressor will see about 1.3% improved efficiency (lower brake horsepower [bhp] per ton) for each degree Fahrenheit the saturated condensing temperature is lowered (e.g., 3 psig for an ammonia system).
Other benefits	Reduces compression ratio on compressors for more hours during a year, thereby reducing compressor wear, helping to extend compressor life.
Stage of acceptance	Many plants have exploited this opportunity by systematically lowering head pressure until a constraint arises. The best practice plants using ammonia refrigeration systems run system head pressures below 100 psig during cool-weather operation.

R2 – Raise suction pressure

Best practice	Raising suction pressure can increase a compressor’s efficiency and deliver significant refrigeration system energy savings. As suction pressure rises, compressor capacity increases while required power increases only slightly.
Primary area/process	Potentially applicable to all industrial refrigeration systems.
Productivity impact	Raising suction pressure lowers compressor horsepower (HP) per ton because the pressure ratio across the compressor is reduced. Additional benefits like expansion compressor capacity gains from raising suction pressures may offset the need to purchase a new compressor.
Economic benefit	Raising suction pressure involves resetting controls along with the possible need to remove components such as evaporator pressure regulators (EPRs). In some cases, electric motors on compressors may need replacement (or imposition of current limits). Work with a refrigeration professional to evaluate whether capital improvements are needed.
Energy savings	As a rule, compressor efficiency increases about 2.5% per degree Fahrenheit increase in saturated suction temperature. Efficiency gains range up to 10%.
Applications and limitations	Many dairies operate at 25 psig suction pressure, corresponding to a saturation temperature of 110˚F. For most dairy operations, this refrigerant temperature is lower than needed for processes and EPRs are added to raise the evaporator pressure/temperature. In nearly all cases, suction pressure can be reset upward with positive impacts.
Practical notes	Some constraints—including verifying compressor motor power capability at the new pressure, oil separator performance and settings of other pressure regulators at a specific suction level in the plant—need to be evaluated to ensure satisfactory system performance.
Other benefits	This practice lowers the compression ratio on high-stage and single-stage (SS) compressors, reducing compressor wear and helping extend compressor life.
Stage of acceptance	Raising suction pressure is a proven high-impact approach to increase plant energy efficiency. However, many plants have overlooked this fundamental opportunity.

R3 – Screw compressor oil cooling conversion: liquid injection to thermosiphon

Best practice	Many screw compressors use high-pressure liquid refrigerant expanded directly into the compressor to cool the oil. This method is called liquid injection, screw, or side oil cooling (SOC). Liquid injection is common practice, but it impairs compressor performance by increasing compressor power and decreasing compressor capacity. The result is lower compressor efficiency. Best practice refrigeration systems use indirect thermosiphon systems to cool oil instead of liquid injection.
Primary area/process	New installations and expansion of existing systems.
Productivity impact	A liquid injection to thermosiphon conversion will provide a small increase in compressor capacity and provides more opportunity to further reduce a system's minimum head pressure.
Economic benefit	The thermosiphon conversion for one Wisconsin industrial refrigeration system with about 5,000 total HP saw a reduction of 9% in compressor and condenser energy use. The simple payback was estimated at three years without incentives. The conversion also freed up nearly 90 tons of high-stage load during peak production.
Energy savings	The efficiency gain from this conversion will be equal to the losses associated with direct injection cooling and varies depending on the compressor design and package. As the pressure decreases, the efficiency benefit from this conversion increases. For suction pressures corresponding to temperatures in the region of 0°F (-18°C), the efficiency penalty for liquid-injection oil cooling is around 5% (see the next table). At suction pressure of 10.4 psig (-40°F/-4.4°C), the liquid-injection oil cooling efficiency penalty increases to more than 15%.
Applications and limitations	Proper refrigerant piping practices are necessary for thermosiphon system operation. An extension of this oil cooling method involves the use of a dedicated and separate refrigerant circuit with its own evaporative condenser.
Practical notes	None
Other benefits	Thermosiphon oil cooling also reduces compressor maintenance compared with liquid-injection oil cooling. This approach provides opportunities to optimize systems by separating oil cooling constraints from system head pressure constraints.
Stage of acceptance	Thermosiphon oil cooling is a proven technology and has been successful on hundreds of industrial refrigeration systems.

R4 – Dedicated condenser for oil cooling

Best practice	Traditional systems rejecting heat from thermosiphon oil coolers involve integrating the refrigerant side of oil cooling heat exchangers with the system's high side. An alternative approach applies one or more dedicated condensers, separate from the system, for the sole purpose of rejecting heat from the oil cooling heat exchangers. The separate refrigerant circuit eliminates the need for non-condensable purging and oil draining required for traditional thermosiphon oil cooling. Energy is saved by rejecting heat from the oil at a higher refrigerant temperature.
Primary area/process	Industrial refrigeration systems using thermosiphon oil cooling for rotary screw compressors.
Productivity impact	Reduces compressor downtime and reduces the likelihood of high side liquid surge and liquid feed problems to loads.
Economic benefit	There is no significant cost difference when it's a new installation. Payback on a retrofit can range from 2-6 years depending on whether existing condenser(s) can be used.
Energy savings	Efficiency benefits vary and can reach 10%.
Applications and limitations	None
Practical notes	Many plants like built-in redundancy. There may be a need to purchase two smaller condensers for oil cooling duty rather than a single larger condenser.
Other benefits	Dedicated thermosiphon oil cooling offers improved safety and reduced maintenance by eliminating the need to drain oil from the refrigerant side of oil cooling heat exchangers.
Stage of acceptance	This best practice has been applied to small systems ranging from cold storage warehouses to extremely large refrigeration systems serving manufacturing facilities.

R5 – Screw compressor sequencing

Best practice	As a screw compressor is unloaded to maintain suction pressure at reduced system loads, the efficiency of a screw compressor decreases. Depending on the part-load operating condition, the reduction in compressor operating efficiency can be significant. Sequencing screw compressors can improve energy efficiency significantly.
Primary area/process	Industrial refrigeration systems using single or twin-screw compressors in either single-stage (SS) or two-stage (TS) compression arrangements.
Productivity impact	Since refrigeration loads vary over time, the capacity of compressor(s) serving those loads must vary in order to maintain a desired suction pressure (temperature) level. Industrial refrigeration systems generally have multiple compressors operating to meet loads which involves a number of sequencing strategies. These sequencing strategies may require modification to improve overall system efficiency.
Economic benefit	Improved sequencing can reduce system energy consumption and reduce wear on screw compressors equipped with mechanism-based capacity controls such as slide valve control. Payback varies with opportunity.
Energy savings	Operating at minimum load could require as much as twice the energy per ton of cooling delivered when compared to operating at full load. It is advised to operate screw compressors at full load to the greatest extent possible.
Applications and limitations	Controlling the sequencing of multiple screw compressors is an opportunity in almost every plant based on the large presence of multiple compressors and the increased use of twin-screw compressors. Outdated controls technology in many plants may limit this opportunity. Modern computer based controls are essential to take full advantage of improved compressor sequencing for peak performance.

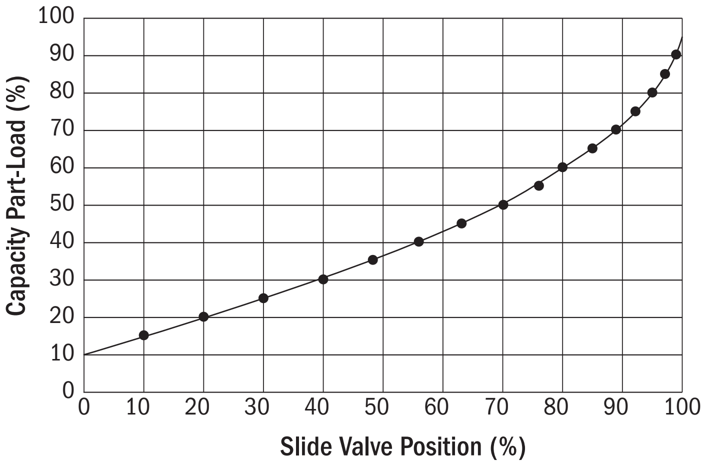
R5 – Screw compressor sequencing (continued)

Practical notes

To determine if improving compressor sequencing is of value to you, note the slide valve position of the screw compressors operating (slide valve position is related to the machine's operating part load condition). If there are one or more machines operating at slide valve positions less than 70%, you likely have an opportunity.

The plot below illustrates the degradation in the efficiency of a twin-screw compressor equipped with slide valve capacity control operating at a suction temperature of 0°F and a saturated discharge temperature of 75°F. At full load, the compressor requires about 1.2 bhp per ton of refrigeration.

When the machine is unloaded to 50% of its full load capacity, the power required increases to 1.5 bhp per ton of refrigeration. At minimum load (12%), the machine's power requirement rises to 4.0 bhp per ton of refrigeration. Operating efficiency declines with part load conditions. The key objective in optimizing the sequencing and control of screw compressors is to avoid prolonged operation of each machine at part load conditions of less than 65%.



Example of the relationship between capacity and slide valve position for one manufacturer's twin screw compressor.

Other benefits

By raising suction pressure, the compression ratio on high-stage and SS compressors is lowered, leading to reduced compressor wear and extended compressor life.

Stage of acceptance

Optimizing the sequencing and controls for twin-screw compressors is readily achievable and effective in improving refrigeration system energy efficiency.

R6 – Manage liquid makeup

Best practice	As the difference increases between the upstream liquid supply temperature and the downstream saturation temperature, the amount of liquid supply flashing to a vapor state (flash gas) during the throttling process increases. Although flash gas is not entirely avoidable, proper application of piping principles and practices can minimize the energy impacts on system performance. Proper piping practices can improve energy efficiency by as much as 8%.
Primary area/process	Many industrial refrigeration plants have multiple suction pressure levels to meet loads. Where a plant has medium and low temperature loads, practices in cascading the makeup liquid through progressively lower pressure (temperature) levels within the system are advantageous.
Productivity impact	Expect to see a slight increase in refrigeration system productivity.
Economic benefit	While dependent on system operating pressures and temperatures, this best practice can improve efficiency by 5% - 10% with paybacks ranging from less than 3 years.
Energy savings	Consider a two-temperature level refrigeration system where the high temperature loads are served by a 25 psig suction pressure (corresponding to a saturation temperature of 12°F) and the low temperature loads are served by a 0 psig suction pressure (-28°F). Two compression configurations are possible: • A system with split suction pressure levels, each having SS compression and both compressors discharging to a common high side pressure. • A compound or TS compression arrangement where the low temperature compressor (booster) operates at 0 psig suction and discharges to an intercooler at the 25 psig suction pressure. A high-stage compressor then raises the vapor at the 25 psig suction pressure to a discharge pressure ranging from 110 - 181 psig, depending on ambient conditions. The supply of liquid makeup to the low and medium temperature loads must be considered. One arrangement is to have high pressure liquid serve both the medium and low temperature loads. You can also throttle the high-pressure liquid first to the medium temperature level (25 psig) and then throttle precooled liquid to the low temperature level of the plant. This piping arrangement has the advantage of reducing the flash gas load on the low temperature compressor.
Applications and limitations	When possible, take advantage of each temperature level in the plant and throttle liquid, successively, from higher to lower pressures. If the lowest operating pressure in the plant is 3.5 psig (-20°F), consider multiple stages of compression as well.
Practical notes	If the lowest operating pressure in the plant is 3.5 psig (- 20°F) or lower, strongly consider implementing TS of compression (if not already equipped). If the plant has multiple suction pressure levels with SS compressors serving each, consider piping the makeup liquid in series from the highest to the lowest pressure level. In cases where there will be one or more intermediate pressure levels in the plant not operating, provide alternative means to get liquid makeup to lower temperature loads.
Other benefits	None
Stage of acceptance	This practice is well established and adopted in many installations although some plants have not fully taken advantage of this opportunity.

R7 – Two-stage compression

Best practice	Consider implementing two (or more) stages of compression for refrigeration systems requiring operation at temperatures below -20°F.
Primary area/process	Applies to all industrial refrigeration requiring low temperature refrigerant to meet space or process load requirements.
Productivity impact	No impact on productivity.
Economic benefit	While retrofits can be done, they can be expensive. The best time to consider a two stage (TS) compression arrangement is early in the process of planning for a new refrigeration system. For new construction, the payback for a TS arrangement can range from 1 - 3 years. As the lowest temperature in the plant decreases, the payback shortens.
Energy savings	TS compression splits the compression process into two distinct steps. As the refrigerant temperature requirement decreases (e.g., lower temperatures), the efficiency gain achieved by moving to TS compression from a SS increases. For a 28°F load, the efficiency improves by 15%. If the load requires -45°F refrigerant, the efficiency gain will exceed 25%.
Applications and limitations	None
Practical notes	None
Other benefits	For low temperature refrigeration systems, conversion from a SS to TS compression will prolong the life of the compressor by substantially reducing the compression ratio of the SS machine.
Stage of acceptance	TS compression systems have been used to meet low temperature refrigeration needs for more than a century. The technology is well established and proven.

R8 – Free cooling

Best practice	Free cooling is the use of the cool ambient conditions to remove heat from process streams without the use of a chiller.
Primary area/process	Free cooling is not process specific.
Productivity impact	None, unless free cooling adds useable cooling capacity.
Economic benefit	The benefit from free cooling comes from allowing automatic controls to turn off the chiller when ambient conditions can meet cooling needs. The economic benefit depends on the chiller load, the electricity rate and the number of hours available for free cooling. Installed costs typically range from $325 to $500 per ton based on system size. Depending on site specific parameters, paybacks typically range from 2 - 4 years in the upper Midwest.
Energy savings	Free cooling potential depends on the hours available for free cooling, which is dictated by process temperature requirements. The following can be used as a guide, assuming installation on fully loaded chillers in Madison, Wisconsin, and a process cooling temperature of 45°F: • 50-ton cooling load: 168,000 kWh per year • 400-ton cooling load: 1,345,000 kWh per year
Applications and limitations	Free cooling benefits are limited by process temperature requirements, the actual load on the chillers and modifications necessary to allow heat rejection to the environment. Existing cooling systems not utilizing direct refrigerant injection are better candidates.
Practical notes	If heat is being recovered from the chiller, this must be accounted for in evaluating project economics. Free cooling systems should be sized to match the installed capacity on a given cooling loop to avoid capacity related issues.
Other benefits	Free cooling can prolong the life of chillers since they do not operate when the system is in full free cooling mode.
Stage of acceptance	This technology is not widely understood.

R9 – Variable frequency drives on evaporator fans

Best practice	Many evaporator fans on refrigeration systems operate at constant speed or are cycled for a regular interval. Variable speed fan operation using variable frequency drives (VFDs) can reduce electricity consumption dramatically.
Primary area/process	This practice applies to variable torque fan loads.
Productivity impact	None
Economic benefit	Payback depends on the amount of time evaporators operate at low part load conditions. The greater part load operation, the greater the savings from VFDs.
Energy savings	At part load ratio of 50%, VFD controls require 20% less power (kW) per ton of refrigeration versus continuous fixed speed operation. For duty cycling at 50%, VFD controls require 9% less power. VFD savings over constant speed operation will likely range from 6% - 10% and savings over duty cycling will range from 3% - 6%.
Applications and limitations	VFDs excel at part load conditions, but savings are only realized when the evaporator is operating at part load. An evaporator operating close to 100% of load for a significant number of hours per year will see less savings with a VFD than an evaporator running more hours at low part load.
Practical notes	The easiest way to control evaporator fans is to operate them continuously to maximize the direct fan energy and parasitic refrigeration load on the space. A more efficient variation on constant speed operation is to duty cycle the fans to maintain setpoints while eliminating stratification. VFDs, modify fan speed as the space temperature deviates from a setpoint. Since reducing fan speed reduces torque, the motor power required drops dramatically compared with constant speed operation.
Other benefits	Fewer system transients, better space temperature control, reduced wind chill, reduced noise, inherently soft start and improved power factor.
Stage of acceptance	Relatively few plants have adopted this best practice.

R10 – Variable frequency drives on screw compressors

Best practice	Screw compressors comprise 80% of the industrial refrigeration market. Staging multiple compressors and the use of a continuous slide valve are two common ways to control compressor capacity. Variable speed operation with VFDs on the compressor motors can reduce electricity consumption, especially where individual compressors operate a significant number of hours at part load.
Primary area/process	Constant speed compressors are least efficient when they are part loaded or unloaded for a significant amount of time. Variable speed compressors with VFDs permit capacity modulation through speed adjustment.
Economic benefit	VFDs in the sizes required to drive screw compressors can be expensive. Payback depends on how much time the compressor is part loaded, likely within 2 - 5 years.
Energy savings	Savings over staged or plug valve capacity control range between 2% - 12% and depend on the existing control strategy and how well it follows load.
Applications and limitations	VFDs excel at low part load conditions but save energy only when the compressor is operating at part load. A VFD on a compressor operating near 100% load for a significant number of hours will see fewer savings than one running more hours at part load. Consider using only one VFD compressor for each plant suction pressure level.
Practical notes	VFDs can be beneficial on screw compressor motors when the compressor is part loaded for a significant amount of time. Additional compressor efficiency can be achieved by lowering the condensing temperature.
Other benefits	Capacity control with a VFD will reduce wear on slide valves and extend the life of the compressor and critical components. A VFD can also provide very stable suction pressures.
Stage of acceptance	Few refrigeration plants have adopted VFDs.

R11 – Variable frequency drives on condenser fans

Best practice	Condenser fans on refrigeration systems primarily operate at constant speed, though they may also be two speed. Variable speed fan operation using VFDs can reduce refrigeration system energy consumption significantly.
Primary area/process	Condenser on a refrigeration system.
Productivity impact	None.
Economic benefit	Payback depends on the amount of time the condenser operates part loaded. This will depend on weather, refrigeration load and condenser capacity.
Energy savings	A system with greater condenser capacity will benefit more from a VFD than one short of condenser capacity. Energy savings will be weather dependent since warm, humid weather requires longer fan run times. Savings over constant speed operation will range from 1% - 5%. Savings over two speed operation is minimal.
Applications and limitations	VFDs excel under part load conditions but save energy only when the condenser has excess capacity or is operating at part load due to cooler outdoor conditions. There is a tradeoff between condenser fan operation and compressor efficiency because longer condenser fan operation can help lower condenser temperature, which improves compressor efficiency.
Practical notes	The most basic and energy-intensive way to control a condenser fan is on/off control with single-speed operation. A more efficient variation is two-speed fan operation with a VFD to better match heat rejection capability to outdoor conditions.
Other benefits	Minimizes fluctuations in system head pressure because the condenser fan motor drive(s) continually modulate the condenser capacity to maintain head pressure. VFDs reduce (or eliminate) the starting and stopping of fan motors to minimize wear on fan belts (if equipped), bearings, shafts and fan blades, and extending the motor life. Operating condenser fans at reduced speed also decreases drift losses from the condensers.
Stage of acceptance	Few refrigeration plants have adopted this technology.

R12 - Door maintenance and management

Best practice	Warm air infiltration into refrigerated spaces through poorly maintained and managed doors adds significant load to the refrigeration system. Perform regular inspection, maintenance and repair of doors and door seals to ensure they work as designed. Also, develop a procedure for door use to minimize door open time and train workers on door operating procedures and expectations.
Primary area/process	Refrigerated docks, coolers and freezers.
Productivity impact	In addition to warming the cold space, infiltration air carries in moisture, which adds to frost problems. Frosted evaporator coils reduce the performance of the evaporators (and cold spaces) and will lead to more defrost time. This reduced performance can slow production as more time may be needed to cool product and, in freezers, more time spent dealing with frost buildup on shelving, product and other surfaces in the space.
Economic benefit	Maintaining door seals, keeping doors in good shape and proper door operating management should be part of a normal routine. The cost for this effort will be offset by the reduced labor needed to clean frost and water from a cold space.
Energy savings	The colder the space requirement, the greater the energy impact of air infiltration. Consider a 12' high by 9' wide overhead indoor door separating a 35°F warehouse from a 65°F, 60% relative humidity warehouse. To address the infiltration air would require about 30 tons of cooling capacity estimated to cost around $2 per hour for each hour the door is open. If a poorly maintained door leaks 5% of the open-door amount when closed, annual cost for a 24/7 operation would be about $70 per year per door. If on average the door was left open an extra 1,000 hours per year, annual costs would be $2,000 per year per door.
Applications and limitations	This opportunity exists for all overhead and side doors used in cold spaces.
Practical notes	Procedures and training are key to success with door management.
Other benefits	Reduced issues with frost buildup minimizes impacts to cooling times and less labor hours labor hours will be needed to maintain the cold space.
Stage of acceptance	Generally practiced by facilities where the impact of poor door practices is understood.

R13 - LED lighting in refrigerated spaces

Best practice	Install efficient LED lighting in refrigerated spaces.
Primary area/process	Refrigerated docks, coolers and freezers.
Productivity impact	LED fixtures have long lives compared to other fixture types and operate better than most in cold conditions reducing maintenance costs.
Economic benefit	For fixture replacement upgrades, ROIs range in the 2- to 3-year range for a 24/7 operation.
Energy savings	Energy savings will occur for the improved efficiency in the light fixture and the reduced internal heat gain from the fixtures in the refrigerated space. As an example, replacing 4’ four-lamp T8 fluorescent fixture with an equivalent 55W LED fixture at a 24/7 facility could save as much as $56 per year.
Applications and limitations	This opportunity exists for all facilities with non-LED fixtures.
Practical notes	To meet FDA requirements, lighting is generally more expensive than it would be in a non-food facility.
Other benefits	Increased life of fixtures reduces cost for maintenance.
Stage of acceptance	This technology is widely accepted.

R14 - Eliminate improper uses for chilled water

Best practice	Eliminate using chilled water to cool processes where cooling tower water could be used as effectively.
Primary area/process	Facilities using chilled water for the cooling water in water cooled air compressors.
Productivity impact	None.
Economic Impact	If other sources of cooling water are available, such as cooling tower water, the cost is limited to the cost of piping cooling tower to the system using the chilled water. ROI would be nearly immediate.
Energy savings	A general rule of thumb is it takes 0.7 kW per ton to chill water with a mechanical chiller and 0.1 kW per ton to chill water with a cooling tower. As an example, an average of 80% or more of the power delivered to run an air compressor is lost in the form of heat in the compressor oil, which then is cooled using water when it's a water-cooled compressor. A 100-HP water-cooled air compressor operating 80% loaded for 7,500 hours per year would require 13.6 tons of refrigeration to cool the oil. The annual electricity cost for chilling this water with a mechanical chiller is $5,700 per year. Using cooling tower water, the cost would be 1/7, or $815 per year. Savings are $4,900 per year, or about $49 per year per compressor horsepower.
Applications and limitations	Recommended for all facilities with water-cooled air compressors using chilled water for cooling.
Practical notes	Rather than cooling tower water, city or well water could be used.
Other benefits	Free upload on the chilled water system for other uses.
Stage of acceptance	Using tower water is widely accepted.

WD1 - Mechanical vapor recompression evaporators

Best practice	Mechanical vapor recompression (MVR) evaporators can save a significant amount of energy over multi-effect thermal vapor recompression (TVR) evaporators. MVR systems can be purchased as a single effect unit or, in some cases, retrofitted to existing systems.
Primary area/process	Whey processing facilities or cheese plants concentrating whey to a shippable product using evaporation.
Productivity impact	No significant production related benefit unless the MVR reduces the load on capacity constrained equipment.
Economic benefit	The cost of a new or retrofit MVR system can be significant and varies with the compression ratio required and system capacity. When determining payback from energy savings, assume gas at \$6.00/1 million British thermal units (MMBtu) and electricity at \$0.055/kWh. The following is a guide to energy savings: • Two-effect with TVR: \$0.0031/lb water removed • Five-effect with TVR: \$0.0008/lb water removed • Single effect with MVR: \$0.0002/lb water removed
Energy savings	Savings vary, but the following can be used as a guide: • Two-effect with TVR: 390 British thermal units (Btu)/lb water removed • Five-effect with TVR: 130 Btu/lb water removed • Single effect with MVR: 32 Btu/lb water removed
Applications and limitations	MVR evaporators are limited to a maximum compression ratio of about 2:1 per stage. Multistage systems can be used for higher ratios, but this increases first cost.
Practical notes	While the energy savings from MVR can be significant, the electric motor driven compressor will require maintenance, an additional expense. Account for this when evaluating payback.
Other benefits	In new installations, the first cost can be lower due to the typically smaller footprint and amount of equipment needed.
Stage of acceptance	This technology is an accepted best practice and has been used for more than 20 years in the dairy industry.

WD2 – Spray dryer heat recovery

Best practice	Recover the hot exhaust often discharged from spray dryers to preheat incoming process air.
Primary area/process	Spray dryers for water-based applications.
Productivity impact	None, unless heat recovery adds useable capacity.
Economic benefit	Depending on the installation, payback can range from 2 - 5 years.
Energy savings	The energy savings depends on the amount of heat exhausted and having an appropriate heat sink such as inlet air. Most fuel savings for most installed systems were approximately 17.7 therms per hour.
Applications and limitations	Economic benefits may be limited by the difficulty of the installation and type of heat recovery system used. In some cases, the heat recovery units must be installed after a filtration device is installed to prevent excessive fouling and sanitation problems. Spray dryer heat recovery requires significant capital, so care should be taken to validate the parameters used for estimates.
Practical notes	Higher fat content materials may be sticky and pose difficulties in cleaning, limiting operating recovery efficiency. Install exchangers where they will not be subject to fouling or use an exchanger able to handle fouling, e.g., glass tube. Leave design and installation of internal exchanger clean in place (CIP) systems to equipment suppliers. When having otherwise skilled staff do the task, poor cleaning, plugging and backup of condensate into the process may result.
Other benefits	None
Stage of acceptance	Some poorly designed installations have caused some to view this technology with skepticism. Trouble free installations, in operation for 15 years, are documented in Wisconsin.

C1 – Reverse osmosis concentration

Best practice	Reverse osmosis (RO) is a cost effective way to increase capacity and reduce energy costs related to whey concentration over single- and multiple-effect evaporators.
Primary area/process	Processing facilities or cheese plants concentrating whey.
Productivity impact	Effectively increases the volumetric capacity of a whey evaporator, increasing the total solids output.
Economic benefit	The cost of a RO system varies with the water removal rate with moderately sized systems cost between \$100,000 - \$150,000. Sometimes stages can be added to existing systems for a cost of about \$40,000. If gas costs \$6.00/MMBtu and electricity costs \$0.055/kWh, use the following as a guide for energy savings: • Two-effect with TVR: \$0.0031/lb water removed • Five-effect with TVR: \$0.0008/lb water removed • Three-stage RO: \$0.00035/lb water removed
Energy savings	Energy savings vary. Use the following as a guide: • Two-effect with TVR: 390 Btu/lb water removed • Five-effect with TVR: 130 Btu/lb water removed • Three-stage RO: 24 Btu/lb water removed
Applications and limitations	RO systems are inherently more efficient than most evaporators and can provide concentration to levels as high as 24%. Consider the potential impact on evaporator hydraulics and the efficiency of thermal vapor recompressors. In some cases, modifications may be necessary.
Practical notes	An existing evaporator to be used after RO must be able to handle the increased solids loading. The maximum final whey concentration from RO is about 24%.
Other benefits	RO is a cost-effective means to increase the capacity of the whey concentration system.
Stage of acceptance	This technology is an accepted best practice and is used extensively in the dairy industry.

SS1 – Heat recovery from continuous boiler skimmers

Best practice	Continuous skimming, also called continuous blowdown, is used to prevent solids buildup. Since the blowdown often goes to drain, a significant amount of energy is available for recovery.
Primary area/process	Low- and high-pressure process steam boilers.
Productivity impact	None, unless heat recovery adds useable capacity.
Economic benefit	This practice recovers waste heat from boiler blowdown to preheat boiler makeup water, feedwater or process water to avoid primary heating costs. Typical installations range from $12,850 - $19,250 and a savings of $2.47 per hour.
Energy savings	In the example above, energy savings are about 615,000 Btu/hr.
Applications and limitations	The economic benefit is limited by the blowdown rate.
Practical notes	Some systems already capture latent heat from blowdown flash steam used in the deaerator. When evaluating project economics, you should account for this factor.
Other benefits	Preheating makeup or feedwater can help reduce thermal shock to the boiler, in some cases reducing stress on tubes. You may be able to minimize the blowdown rate or shift from intermittent to continuous blowdown to even out the heat transfer rate. Ideally, consider these options upfront.
Stage of acceptance	This technology is generally understood and accepted.

SS2 – Boiler exhaust heat recovery with condensing economizer

Best practice	Industrial process boilers lose 15% - 20% of the fuel heat through stack gases. Condensing economizers can be used to cool and condense the exhaust water vapor, increasing boiler efficiency by 5% - 10%.
Primary area/process	Low- and high-pressure process steam boilers.
Productivity impact	None unless heat recovery adds useable boiler capacity.
Economic benefit	This practice recovers waste heat from stack gases to preheat boiler makeup water, feedwater or process water, avoiding primary heating costs. Paybacks range from 1 - 3 years depending on the type of condensing economizer used and the fuel rate. Direct contact units are less expensive than indirect contact units.
Energy savings	Energy savings depend on the quantity and temperature of the condensing medium available and the temperature requirements of the water leaving the economizer. Assuming an average steam rate of 20,000 pounds per hour (pph), a pressure of 100 psig and a rate of $8.00/MMBtu, a 10% efficiency gain yields about $17.60/hr or 2.2 MMBtu/hr.
Applications and limitations	Some operators resist direct contact systems because the flue gas meets the condensing water, entraining some of the flue gas constituents. This is a concern with systems able to fire fuel oil or natural gas and can be addressed by incorporating a separate heat exchanger.
Practical notes	One system may be better than the other depending on temperature requirements. Since condensing economizers cause condensation, they are designed to handle corrosion and are not subject to the cold end condensation problems common to non-condensing feedwater economizers.
Other benefits	Preheating makeup or feedwater can help reduce thermal shock to the boiler, in some cases reducing stress on tubes.
Stage of acceptance	This technology is not widely understood but is gaining in popularity.

SS3 – Initiate a steam trap program

Best practice	Scheduled checking of steam traps has been considered a best practice for many years. The repair and replacement of leaking traps can significantly reduce steam costs.
Primary area/process	High and low pressure non-pressurized condensate return systems.
Productivity impact	None unless leaking traps allow enough steam to be lost to impact process operations due to reducing effective capacity.
Economic benefit	An inverted bucket trap with a ¾-inch body and ¼-inch orifice will pass about 700 pph of live steam in a failed open position. Assuming each pound of steam passing the trap leaves the steam system, a fuel at $7.00 per MMBtu and a boiler efficiency of 80%, this costs $7.00 per hour. In a process operating 4,000 hours per year, the leaking trap is responsible for a cost increase of $28,000.
Energy savings	For the example, the energy loss is about 1.01 MMBtu/hour.
Applications and limitations	This best practice applies to any steam system with a vented condensate collection system. Although all traps can fail open, target inverted bucket and disc traps first.
Practical notes	Electronic equipment can help determine if a steam trap has failed open. For a proper diagnosis, find out what type of trap is being evaluated. Make a map of your facility indicating the type of trap, make, age, body size and orifice size. Look at the stack on the condensate vent tank. A normal condition is usually indicated by a gentle wafting of steam from the stack (this is flash steam). High-velocity steam usually indicates one or more traps passing live steam.
Other benefits	None
Stage of acceptance	This practice is well documented and accepted.

SS4 – Boiler pressure reduction

Best practice	Many dairy facilities generate steam at higher pressure and reduce the pressure to match the load for a particular unit operation. Lowering boiler steam generation pressure to better match process requirements will reduce energy costs about 1% for each 40°F stack temperature can be lowered.
Primary area/process	Low- and high-pressure steam plant boilers.
Productivity impact	None.
Economic benefit	Generally, payback is immediate if controls or other equipment do not require modification or replacement. Payback depends on the size of the boiler and the amount of turndown possible. A 200 HP boiler allowing turn down from 110 psig to 60 psig could see a cost savings of $1,400 per year at a fuel rate of $4.00 per MMBtu.
Energy Savings	For the example above, the energy savings were estimated at 347 MMBtu per year.
Applications and limitations	Reducing pressure too much can cause carryover, resulting in wet steam. Incremental reductions are recommended with guidance from the manufacturer as necessary.
Practical notes	Since stack temperatures are usually 50°F - 100°F above steam temperature, savings can be easily estimated from the difference in steam temperatures. For the example above, the temperatures of 110 psig and 60 psig steam are approximately 344°F and 308°F, respectively.
Other benefits	Less heat loss in the steam distribution system.
Stage of acceptance	This practice is widely understood.

PH1 – Select proper heat exchanger for pasteurizer

Best practice	Pasteurizers typically use a heat exchanger to heat water for pasteurization of whey, raw mixes and milk. Depending on your system configuration and type of exchanger, you may be able to replace the existing heat exchanger with one allowing a lower approach temperature and still meets production needs.
Primary area/process	Any system using pasteurization.
Productivity impact	Usually none, unless the hot water temperature can be reduced, minimizing the chance of burn on.
Economic benefit	Payback depends on lowering energy costs for water heating, reduced pump pressure drops or flow rates. The Focus on Energy study found in Appendix X showed a savings of $2.96 per hour at $4.00 per MMBtu and a boiler efficiency of 80%. Payback, based only on the thermal energy savings, was estimated at 4 years.
Energy savings	Lowering the approach temperature by improving the heat exchanger can save thermal energy, especially if the outlet hot water is discharged to the drain. In the study mentioned above, the energy savings were estimated at 740,000 Btu per hour. Reducing flows through throttling or using VFDs may allow a reduction in electricity used.
Applications and limitations	Shell and tube exchangers generally offer more opportunity for improvement than plate and frame exchangers. However, plate and frame exchangers can also be improved.
Practical notes	Make sure reducing the inlet hot water temperature will provide a reduction and not just shift the load from one point to another.
Other benefits	Reducing hot water temperatures can reduce burn on of minerals on the product side of the exchangers.
Stage of acceptance	This practice is well documented and accepted.

G1 - Metering and monitoring for energy efficiency and cost reduction

Best practice	Metering and monitoring refer to the use of portable or permanent devices to provide selected information about a process stream or piece of equipment. The information tracked usually includes energy (kWh), power (kW), flow, flow rate, temperature and pressure.
Primary area/process	This best practice applies to any energy conversion process, including manufacturing, production and building technologies.
Productivity impact	Production impacts are possible, depending on the application.
Economic benefit	A Wisconsin dairy considered replacing a 20-year-old VFD on an MVR. Power metering showed replacing the drive would offer no gain in efficiency. The facility avoided $50,000 in drive replacement costs.
Energy savings	Metering and monitoring provide no direct energy savings unless the results are used to make the indicated improvements. Energy savings will vary with the indicated improvement.
Applications and limitations	Metering and monitoring data can be done by itself or in conjunction with simple estimates or detailed engineering analysis to determine value of potential projects.
Practical notes	In some cases, application of metering and monitoring will require strategic planning to determine the best locations for meters and the best way to use and present the data.
Other benefits	With proper placement, metering and monitoring can also be used to develop awareness and allocate utility costs at facilities using business units or cost allocation centers.
Stage of acceptance	This practice is generally accepted as the most effective method to determine actual energy savings and which areas of a facility or process are most appropriate to target for efficiency improvement activities.

G2 - High efficiency agitator motors

Best practice	Many dairy facilities still use motors on older and inefficient agitators when compared with current models. Since agitator motors typically operate near full load, it often makes economic sense to replace the motor with a premium version.
Primary area/process	Whey pasteurization and other mixing applications.
Productivity impact	None
Economic benefit	The benefit comes from using a higher efficiency motor. Typical paybacks range from 2 - 3 years depending on operating hours. A 20 HP agitator motor with a nameplate efficiency of 87.5% can be replaced with a premium motor with an efficiency of 93%. With 6,000 annual hours of operation, a load factor of 90% and an electric rate of $0.05/kWh, the energy savings is $272 per year and the simple return on the motor cost is 2.7 years.
Energy savings	In the above example, the energy savings is 5,446 kWh per year.
Applications and limitations	Non-agitator motors are also candidates. Older motors larger than 75 HP may already have relatively high efficiencies and replacement may be less economically beneficial.
Practical notes	Older motors ready for replacement will offer better returns because they will need replacement regardless. Where smaller motors (< 10 HP) are substantially part loaded, the economic benefit will be greater due to the poor part load efficiency of smaller motors.
Other benefits	None
Stage of acceptance	This technology is widely understood and generally utilized.

APPENDICES

Appendices

Appendix A

Appendix B

Appendix C

Appendix D

Appendix E

Appendix A

Industrial support system best practices

The following are key energy best practices for common supporting systems in industrial facilities. Contact Focus on Energy for more information on these best practices, free technical support to estimate the best practice energy savings for your systems and possible financial incentives.

Compressed air	• Reduce system pressure • Repair leaks • SS vs. TS	• Variable inlet volume • Variable speed control • Energy-efficient motor
Lighting	• Light meter used to verify levels • LED lighting • Occupancy sensors • Lights off during process shutdown	• Task lighting is maximized • Night lighting is turned off • LED exit signs
Motors	• Premium efficiency motor vs. repair • Cogged belts vs. V-belts	• Premium efficiency motors specified on new equipment
Pumps	• Trim impeller to meet maximum load • Use variable speed drive (VSD) instead of throttled control • Use VSD instead of bypass control	
Area comfort heating	• Reduce waste heat • De-stratify heated air in plant • Control heating to desired temperature • Use infrared heating	• Optimize cubic feet per minute air exhausted • Automatic temperature control • Minimize heat to storage areas
Comfort cooling	• Install removable insulation • Minimize unnecessary ventilation • Minimize moisture released	• Higher efficiency air conditioning • Optimize room air temperature
Dehumidification	• Reduce humidity load • Accurately controlling humidity • Optimize ventilation	• Desiccant dehumidification • Minimize reheat energy
Refrigeration	• Thermosiphon • Evaporator fan control • Floating head pressure • Scheduled maintenance – Clean filters – Low refrigerant charge	• Automatic air purge • Recover flash steam

Steam systems	• Reduce steam pressure • Steam trap maintenance • Minimize blowdown • Insulate pipes	• Improve boiler efficiency • Heat recovery for boiler blowdown • Increase condensate return • Stack economizer
Ventilation	• Direct fired make-up units • Better ventilation management	• De-stratified air
Wastewater	• Fine-bubble diffusers • Automatic controlled DO sensors/VSDs	• Heat recovery on anaerobic digester • Unneeded aeration basins are shut off
Fan systems	• Reduce excess flow • Eliminate flow restrictions • Correct poor system effects	• Optimize efficiency of components • Correct leaks in system • Optimize fan output control
Process cooling	• Use VFDs • Float head pressure • Use of free cooling (fluid cooler) • Use of free cooling (cooling tower)	• Match chilled water pumps • Insulate pipes and vessels • Process to process heat recovery
Process heating	• Optimize combustion air fuel ratios • Preheat combustion air • Insulate pipes and vessels • Schedule cleaning of heat exchangers	• Condensing heat recovery • Process to process heat recovery • Ultra-filtration for condensation
Vacuum	• Optimize total cost for conveying • Choose appropriate vacuum pump	• Optimize vacuum pressure • Eliminate vacuum leaks

Appendix B

Average energy use per ton of product

Table 1: Average energy use per ton of product

PRODUCT	PROCESS	ENERGY CONSUMPTION (%)	MMBTU/TON OF PRODUCT[1]
Butter	Cooling	66%	1.25
	Compressed Air	8%	0.15
	Cleaning in Place	26%	0.49
	Total	**100%**	**1.89**
Cheese	Reception/Thermization	19%	0.70
	Cheese Processing	14%	0.52
	Cheese Treatment/Storage	24%	0.89
	Cooling	19%	0.70
	Compressed Air	5%	0.19
	CIP	19%	0.70
	Total	**100%**	**3.70**
Fluid Milk	Reception/Thermization	2%	0.02
	Storage	7%	0.07
	Centrifugation/Homogenization/Pasteurization	38%	0.36
	Packing	9%	0.09
	Cooling	19%	0.18
	Compressed Air	0.50%	0.0
	CIP	9.50%	0.09
	Process Water	6%	0.06
	Space Conditioning	9%	0.09
	Total	**100%**	**0.96**
Milk Powder	Thermization/Pasteurization/Centrifugation	2.5%	0.24
	Thermal Concentration/Evaporation	45%	4.30
	Drying	51%	4.88
	Packing	1.5%	0.14
	Total	**100%**	**9.56**

Source: Adapted from Energy Use and Energy Efficiency in the European Dairy Industry, Ramirez, et. al. 2004

To compare your facility's baseline energy use to the values in Table 1 (above):

1: Convert annual kWh to $\text{MMBtu}_{\text{ELECTRIC}}$: [kWh x 3413 Btu/kWh] / 1x106 Btu/MMBtu = $\text{MMBtu}_{\text{ELECTRIC}}$
2: Determine total baseline energy, $\text{MMBtu}_{\text{GAS}} + \text{MMBtu}_{\text{ELECTRIC}} = \text{MMBtu}_{\text{TOTAL}}$
3: Divide the results from 2 by your annual primary production (in tons).

Appendix C

Refrigeration energy efficiency improvement potential checklist

(Courtesy of the IRC)

Compressors

- Reduce head pressure
  - Floating head pressure
  - Fixed head pressure
- Raise suction pressure
- Compressor sequencing

Operations

- Implement load shifting
  - Review utility rate structure
  - Battery charging off-peak
  - Others
- Improve defrost control strategy
  - Defrost off-peak
  - Stagger defrost
  - Optimize defrost time/energy input
  - On a need basis rather than timed

Compressors

Reduce head pressure

There are several reasons why compressor discharge pressure (head pressure) can be artificially high. Some quick checks include:

- Condenser
- Defrosting
- Direct expansion (DX) evaporators
- Liquid injection oil cooling
- Screw compressor oil separator sizing
- Evaporative condenser selection
- Compressor selection
- High pressure liquid piping
- Hand expansion valve settings
- Gas driven equipment
- Controlled pressure receivers
- Heat recovery

Condenser operation

Fans	Are they all working? Do you have variable or multi-speed fans? • Are they used to control head pressure?	Is there anything blocking fans from effectively moving air? • Walls • Blocked/bent/scaled louvers	Are the fan drive systems in good working order? • Shaft/shaft bearings • Motor

Coils	Are the coils free of debris?
	• Biological/scale buildup
	• Clean coils semiannually if this is a problem
		Do you have an evaporative condenser?
		• Are all of the coils being wetted?
		  • Intermittently wetted? Look for severe scaling here.
		• Dry spots?
		  • Check spray nozzles for obstruction
		  • Consider adding more nozzles if necessary	

Hot gas defrosting requirements

Do you have defrost relief valves open at 75+ vpsi?	Consider lowering this pressure if defrost time remains within specification
Are your defrost supply mains and evaporator runouts undersized?	Pressure drop in defrost lines can be a limiting factor to further dropping head pressure
Do you use DX evaporators?	The thermostatic expansion valve (TXV) commonly requires a 75-psi pressure drop across it, which can limit the minimum head pressure allowed • Consider swapping TXV for electronic expansion valves or a motorized valve • Consider swapping out evaporators for liquid overfed or flooded evaporators
Do you use liquid injection oil cooling?	Liquid injection oil cooling (SOC) typically requires a 100-psi pressure difference across the TXV, which can limit head pressure to around 130 psig • Consider using thermosiphon oil cooling
Is your oil separator adequately sized?	Lower head pressures will result in higher gas velocity through the oil separator at full load conditions • If oil separation becomes a problem during low head, full load operation, consider upsizing the oil separator to decrease gas velocity through it and allow the oil to fall out
Is your evaporative condenser adequately sized?	If you are not meeting load at a given lowered head pressure, you may have undersized condensers and will have to maintain a higher head pressure until there is more condenser capacity (condenser sizing is discussed in more detail in Sec. 4.2 in IRC's Industrial Refrigeration Systems Energy Efficiency Guidebook) (see the end of Appendix C for a link to this resource)
Does your compressor have a fixed or variable volume ratio (Vi)?	If you have a fixed Vi screw system and the compressor discharge pressure is severely mismatched with the operating high side pressure, an energy penalty will be incurred (Note: screw compressors are the only compressor type having such a constraint
Are your loads fed with high pressure liquid?	Your ability to supply evaporators with cold liquid will diminish with decreasing head pressure. It may become necessary to artificially pressurize the high-pressure liquid supply line to achieve the necessary flow rate into the evaporators
As head pressure drops, are hand expansion valves set properly?	The pressure drop requirement across the hand expansion valve decreases with falling head pressure. Manual reset of hand expansion valves may become necessary in order to meet load
Do you have pumper drums (gas driven liquid transfer systems)?	The ability to transfer liquid using pumper drums becomes diminished as head pressure drops. In order to safely transfer liquid and continue to decrease head pressure, it may be necessary to change to a liquid refrigerant pump
Do you have controlled pressure receivers (CPRs)?	It may become difficult to maintain pressure in a CPR while decreasing head pressure • Pressure regulator may not be sufficiently sized • Try adding a separate parallel valve train with an alternative regulator selection activated when head pressure drops • May want to consider substituting CPR for a mechanically pumped recirculator package
Do you run into heat recovery problems as head pressure falls?	If heat recovery is an obstacle not allowing head pressure to drop, consider generating heat elsewhere rather than penalizing the entire refrigeration system. The penalty associated with maintaining head pressure for heat recovery far outweighs that of heat generation

Raise suction pressure

Raising suction pressure is more complicated because it may have a direct impact on product quality depending on the application. The benefits of raising suction pressure are substantial. An increase in suction pressure by 1°F can increase compressor capacity by about 2.5% as a rule of thumb. It may be worthwhile to check suction pressure three or more times per day to set it at a maximum while still providing enough cooling.

The following are potential constraints of raising suction pressure:

- Compressor motor sizing
- Oil separator sizing
- Suction line pressure drop
- Vessels
- Valves

Is your compressor motor sized to handle full load conditions with an increase in suction pressure?	Often, a motor will be oversized for a compressor at initial design suction pressure, but it is important to make sure the motor is sufficient for full load conditions at higher suction pressures • If it is not, consider changing the maximum slide stop position so compressor full design load is never met • If you have a belt driven system, consider changing a pulley to keep motor load lower
Is your oil separator adequately sized?	Lower head pressures will result in higher gas velocity through the oil separator at full load conditions • If oil separation becomes a problem during low head, full load operation, consider upsizing the oil separator to decrease gas velocity through it and allow the oil to fall out
Are your suction lines adequately sized?	Utilizing increased compressor capacity as suction pressure is reduced will result in higher-pressure drop-in suction lines. Undersized suction lines will penalize a portion of the efficiency gains realized by increasing suction pressure (note: under the same mass flow conditions at higher suction pressures, pressure drop will fall)
Are your vessels adequately sized?	If you are raising suction pressure for improved energy efficiency only, then vessel sizing should be adequate as is. If by raising suction pressure you are attempting to raise capacity, then vessel sizes must be re-evaluated
Are your valves suitable for low pressure differences encountered in elevated suction pressure conditions?	You may need to make sure your EPRs have a sufficient pressure difference across them. These valves typically have a minimum required pressure drop for stable control. Aside from changing out the valves, there are other energy efficiency improvements like removing EPRs entirely

Compressor sequencing

Compressor sequencing is a no-cost way of reducing energy consumption related to part load compressor inefficiency particularly with screw compressors. The following are general guidelines for compressor sequencing (Manske, et al., 2002):

- If you use a reciprocating and a screw compressor, utilize load following with reciprocating
  - Reciprocating compressors have much better part load operating characteristics than screws
- If you are using two screws to share the load, avoid allowing one or both compressors to operate below 50% load
  - Screws should be sequenced so they are running at or as close to part load as possible
- If you use multiple reciprocating compressors to share the load, the load should be shared equally
- Compressors with unequal capacities have different optimal sequencing than those with equal capacity
  - There are a few helpful examples in Section 6.3 of the IRC's Industrial Refrigeration Systems Energy Efficiency Guidebook (see the end of Appendix C for a link)

Operations

Implement load shifting

Review utility rate structure

Utility rate structures reward energy consumption at off-peak hours of the day. Shifting refrigeration loads to off-peak times can result in a substantial savings. It is also important to analyze your rate plan to determine whether it is more important to have relatively flat energy consumption or consume a bulk of the energy off-peak, not worrying about peak demand. Typically, you will be charged based on your total energy consumption and on your peak demand, so it is important to determine what peak loading scheme and energy demand profile will result in the largest savings.

RATE PLAN A						RATE PLAN B	
Peak Power Usage Charge:	$/kW	Current Peak Power Usage:	kW	Target Peak Power Usage:	kW	Peak Power Usage Charge:	$/kW
Energy Usage Charge:	$/kWh	Current Energy Usage:	kWh	Target Energy Usage:	kWh	Energy Usage Charge:	$/kWh

Ideal Rate Plan: ☐ Plan A ☐ Plan B

Battery charging off-peak

Battery charging should be conducted during off-peak hours outside of any refrigerated or conditioned space if possible. This is an energy-intensive process potentially adding significant heating loads on a refrigeration system and can increase peak power usage.

Improve defrost control strategy

Defrost controlling can be a complex study, but there are a few relatively simple things that can be done to potentially reduce the cost of defrost and improve energy efficiency.

- Defrost off-peak so the refrigerated space is pulled back down to normal conditions during times of low energy demand and reduced utility rates.
- If possible, stagger defrost of evaporators so no two are in defrost at any time. This decreases pressure drops in defrost line headers.
- Reduce hot gas defrost pressure as low as possible to avoid heating evaporator coils and the refrigerated space unnecessarily. You may also find defrost times do not need to be lengthened despite lower hot gas temperatures. Make sure all the ice is melted from the surface of the coils but also defrost does not continue beyond this point.
- It may not be necessary to use hot gas as a defrost method. If the cooled space temperature is above 38°F - 40°F, consider allowing ice to melt using ambient air.
- Defrost system on a need basis rather than on a timed basis. Take some time to observe how long it takes for ice build-up on cooling coils to become detrimental to evaporator operation. Defrosting before ice on coils is a problem that can severely penalize the energy efficiency of the system.

Click here to learn more about the IRC's Industrial Refrigeration Systems Energy Efficiency Guidebook.

Appendix D

Engineering case study #1

Consider reverse osmosis to complement evaporation

Reverse Osmosis (RO) is a membrane separation process using high-pressure pumping instead of evaporation to concentrate product and has much lower energy costs than evaporation. While RO is proven for many industrial applications, this case study addresses the application of RO to whey processing. The following analysis derives from metered data and collaboration with the original process and equipment designers.

Generally, in new design, RO can concentrate whey from 6% up to about 24%. However, in retrofits where RO is used on the front end of an evaporator, evaporator performance may limit the final concentration unless appropriate modifications are installed. Consider a multi-effect evaporator currently concentrating whey from 6% - 24%. The evaporator designer indicates the upper limit for the whey feed concentration delivered to the evaporator is likely about 12% to avoid operational problems. In this case, RO can be used to concentrate whey from 6% - 12%. The evaporator can then concentrate the whey from 12% - 24%.

RO system

The opportunity

When a Wisconsin dairy learned a RO system could provide energy savings and increase production, the company decided to evaluate the potential relative to its existing RO system. The existing system was installed in the mid-1990s to increase whey concentration capacity. An evaluation indicated the solids concentration could be increased by up to 2.5% without harm to the RO unit or the performance of the multi-effect evaporator. The evaluation reported this could be done simply with control setpoint changes. The evaporation process was modeled with process log data and original system design data to determine the potential energy savings. Since no other reliable way to estimate the steam flow used by the evaporator existed, modeling was used. The RO system was evaluated by metering the main power to the RO system.

This data represents the operation of the RO system during both processing and non-processing periods. The results of the analysis of the evaporator and the RO system during processing are summarized in Figure X.

Current RO and evaporator conditions

SYSTEM	MOTIVE STEAM* (LB/HR)	ELECTRIC POWER (KW)	BTU/LB OF WATER REMOVED	$/LB WATER REMOVED**
5-Effect Evaporator with TVR	6,300	0	131	$0.00079
3-Stage RO	0	170	23.6	$0.00035

*Motive steam load adjusted to account for apparent inefficiency of existing TVR. Condensate at 160 F is assumed to result from condensation of the motive steam. All condensate from the evaporator is assumed to be beneficially used elsewhere in process operations.

**These numbers include energy costs only. Natural gas at $6.00/MMBtu, electricity at $0.05/kWh and 4,500 hours per year average process operation time. Any water disposal charges have not been included.

NOTE: Maintenance was 38% higher for evaporation, including chemicals for CIP and membrane costs.

The solution

The analysis indicated the water to be removed by evaporation would lessen by about 17%, yielding estimated energy savings of more than $20,000 per year. Estimated payback is immediate.

Project benefits

RO can be a very cost-effective way both to increase the capacity of a process and reduce energy costs. In some cases, RO may completely offset the need for evaporation where evaporation is used to provide a final concentration of less than 22%.

Engineering case study #2

Improving pasteurizer performance

The pasteurization of whey is an energy-intensive process heating whey to approximately 170°F, usually in a large plate and frame heat exchanger. The heat source is usually condensate from the whey concentration process such as from evaporation. Since the condensate temperature ranges from 140°F - 160°F, it must be heated to about 185°F - 190°F before entering the plate frame exchanger.

Once process needs have been met, a plate and frame heat exchanger is frequently purchased because of low first cost. For this case study, an efficient exchanger is one using a lower temperature source and still raising the whey temperature to levels required for pasteurization.

Heat exchanger efficiency is usually expressed in terms of its approach temperature or effectiveness. Reducing the approach temperature improves the heat exchanger efficiency. As a rule, plate and frame heat exchangers are capable of a lower approach temperature than shell and tube exchangers. However, even plate and frame heat exchangers can be improved.

The opportunity

A Wisconsin dairy facility wanted to identify process energy efficiency opportunities and replacement of the whey pasteurizer heat exchanger was identified as a potential opportunity. The heart of the pasteurizer is the plate and frame heat exchanger. The original exchanger was installed with low first cost in mind. After years of operation, one of the plates had developed a leak and was scheduled for replacement. However, after looking at performance parameters, it was determined the approach temperature was much higher than possible for this type of unit. The high approach temperature also required a higher water temperature for heating the whey, which caused whey burn on. Furthermore, a large amount of potentially useful energy was being carried away in the wastewater.

The solution

Since the water passing through the heat exchanger is sent to the drain after heating the whey, lowering the approach temperature of the water would have the effect both of saving energy and reducing the risk of whey burn on. The facility elected to replace the entire heat exchanger rather than replace only a single plate. This decision was based largely on production improvements and the long expected lifetime of the equipment. Plus, the economics made sense. The existing heat exchanger temperatures, projected temperatures and expected energy savings are provided in the table below.

PARAMETER	EXISTING	PROJECTED
Condensate of whey (COW) water temp (˚F)	190	185
Whey entering temp (˚F)	162	162
Energy savings (MMBtu/hr)	-	0.763

PROJECT SUMMARY	
Project Cost (est)	$65,000
Energy Savings (est)	$24,000
Energy Payback	2.7 yrs

Project benefits

The table above indicates replacement of the existing plate and frame heat exchanger with a unit allowing a lower hot COW water temperature for whey pasteurization can save energy. In addition to saving an estimated 4,119 MMBtu per year, the lower approach temperature reduces the chance for whey burn on. Reducing burn on potential helps with product quality, and helps prevent fouling and related energy increases resulting as controls try to overcome the increased resistance to heat flow.

At $6.00/MMBtu, the new equipment provides an estimated annual savings of $24,000 with a simple payback of 2.7 years. This payback does not include additional dollars from a Focus on Energy incentive, which encouraged the facility to install the new pasteurizer exchanger.

Note: If the hot water leaving the pasteurizer was already used elsewhere in the process, some or all of the potential savings may not have been realized. Only careful process analysis can ensure the likelihood of projected savings.

Engineering case study #3

Meter and monitor to verify savings before implementation

Metering and monitoring refer to the use of portable or permanent devices to provide selected information about a process stream or piece of equipment. The information to be tracked depends on what it will be used for but also, can include electricity use (kWh), power (kW), total flow, flow rate, temperature and pressure. These parameters may be metered for a short time to obtain a snapshot or monitored for an extended period to provide baseline information about how a process or piece of equipment is operating. This type of information can be very valuable on a stand-alone basis or when used in conjunction with simple estimates or advanced analysis to identify the economic value of potential projects. In some cases, it can also be used to help develop awareness and to understand the allocation of utility costs. This case study reviews three specific projects considered at Wisconsin dairy facilities where metering was used.

Opportunity 1 - Variable frequency drive efficiency

A medium to large size Wisconsin dairy facility was considering the replacement of the existing VFD on the MVR used on their multi-effect evaporator. The unit was roughly 20 years old and operators believed a newer drive would be more efficient.

The solution

Two Dent ELITEpro three-phase logging power meters were used to determine the operating efficiency of the drive. One was placed on the alternating-current line to the VFD and the other between the VFD and the MVR motor. The two meters were synchronized. Figure 1 summarizes the results of the metering.

The monitoring showed the VFD efficiency was satisfactory, well within the expected range, even for a new drive. Replacing this drive based on efficiency would likely provide no energy savings. Since the new drive would cost between $50,000 - $60,000, it would not be cost effective. Often equipment in service for many years can wear and perform at a lower efficiency than when new. The staff's willingness to perform this assessment saved the company a considerable investment in a new VFD.

Metering also helps address power factor correction, often linked to the use of VFDs. Significant power factor charges from the electric utility can motivate a facility to correct its power factor. Figure 2 below shows the positive impact the VFD has on power factor. In other applications, metering has shown VFDs can improve power factor from about 60% to as high as 92%.

Opportunity 2 – Exhaust heat recovery

Process heat recovery systems can be expensive. Often these systems are purchased and installed based on design assumptions, nameplate equipment data or using data from process control rooms. Often, the actual conditions a heat recovery system sees varies considerably from these assumptions. Sometimes process flows are overlooked due to the complexity of the processes involved, inadequate instrument calibration, substantially oversized equipment or equipment not operating at design because it is worn from years of reliable service without the need for maintenance.

The solution

Table 1 gives an example where metered data were considerably different from anticipated values. Note the impact on hourly savings. The discrepancy was initially identified through engineering modeling of the process with metered data as inputs. The missing flow was identified after the discrepancy was found. Although this is a very good project, future efforts can suffer when anticipated savings are too far from what is realized. While it is sometimes very difficult to verify energy savings, particularly with the utility meter as the guide, efforts upfront can help ensure accurate data are used in assessing projects.

Table 1. Anticipated vs. Measured data

PARAMETER	ANTICIPATED	MEASURED / VALIDATED
Annual Operating Hours	7,280	6,934 (BIN data)
Inlet Air Flow Rate (scfm)	40,700	15,984
Exhaust Temperature (°F)	195	178.3
Exhaust Air Flow Rate (scfm)	45,515	38,074
Exhaust Temperature Leaving Exchanger (°F)	109	138.3
Preheated Air Temperature (°F)	138.4	~148
Hourly Energy Savings (therm/hr)	40.6	17.7
Hourly Energy Cost Savings ($/hr)	$28/hr	$12.40/hr

Appendix E

Additional resources

1. Industrial Refrigeration Consortium: www.irc.wisc.edu
2. Food Northwest: www.foodnorthwest.org
3. Natural Resources Canada: www.nrcan.gc.ca
4. Office of Energy Efficiency & Renewable Energy: www.energy.gov/eere/office-energy-efficiency-renewable-energy
5. Focus on Energy: www.focusonenergy.com

Notes

REDUCING ENERGY WASTE ACROSS WISCONSIN

FOCUS ON ENERGY®, Wisconsin utilities' statewide program for energy efficiency and renewable energy, helps eligible residents and businesses save energy and money while protecting the environment. Focus on Energy information, resources and financial incentives help to implement energy efficiency and renewable energy projects that otherwise would not be completed.

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