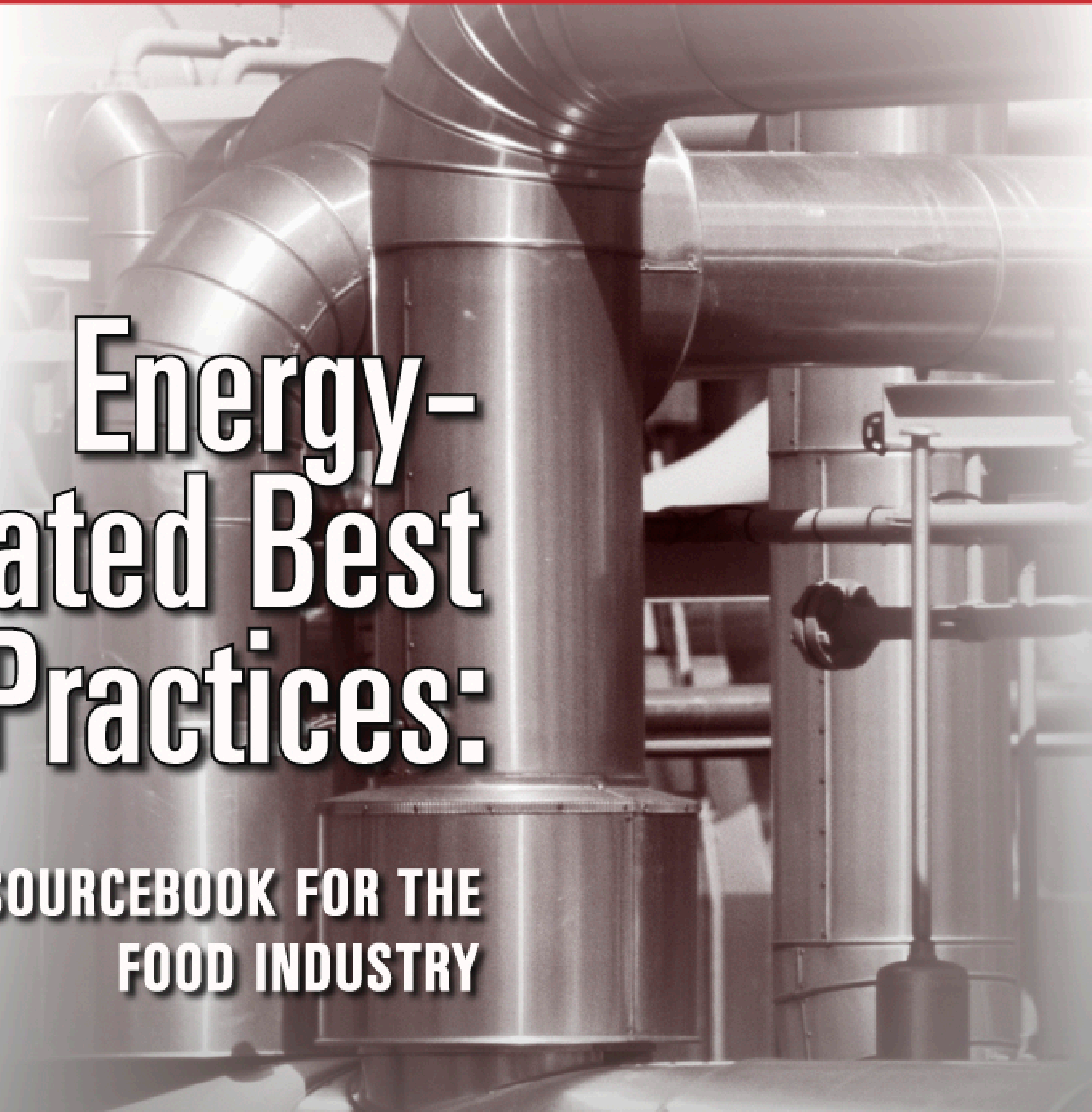
IOWA STATE UNIVERSITY
University Extension



Energy-Related Best Practices:

A SOURCEBOOK FOR THE FOOD INDUSTRY

Energy-Related Best Practices:

A Sourcebook for the Food Industry

Coordinated by:

ciras

October 2005

ACKNOWLEDGEMENTS

Many people have contributed to the creation and publishing of this document. Special thanks are extended to the individuals and companies noted below.

- Iowa Energy Center, Ames, especially Bill Haman, P.E., Industrial Program Manager
- Industrial Assessment Center at Iowa State University, Ames
- Anderson Erickson, Des Moines, especially Norm Dostal, Frank McDowell, and Bruce Schultz for allowing the project team to visit their site while developing the refrigeration section
- General Mills, Cedar Rapids, especially John Burgess, Paul Lemke, Greg Godsey, and Mark Hindman for allowing the project team to visit their site while developing the materials for the steam section
- Tyson, Waterloo Complex, especially Tim Schelle and Ed Albert (and Angela Wakeland in Madison, NE) for allowing the project team to visit their site while developing the steam and refrigeration sections
- George Briley, Technicold Services, Inc., San Antonio, TX, for his contributions to the refrigeration section
- Kelly Paffel, Plant Support & Evaluation, Inc., Naples, FL, for his contributions to the steam section
- Ronald Cox, Director, CIRAS, Iowa State University Extension
- Alexandre Kisslinger Rodrigues, CIRAS, Iowa State University Extension
- Tim Sullivan, CIRAS, Iowa State University Extension

TABLE OF CONTENTS

1. Introduction

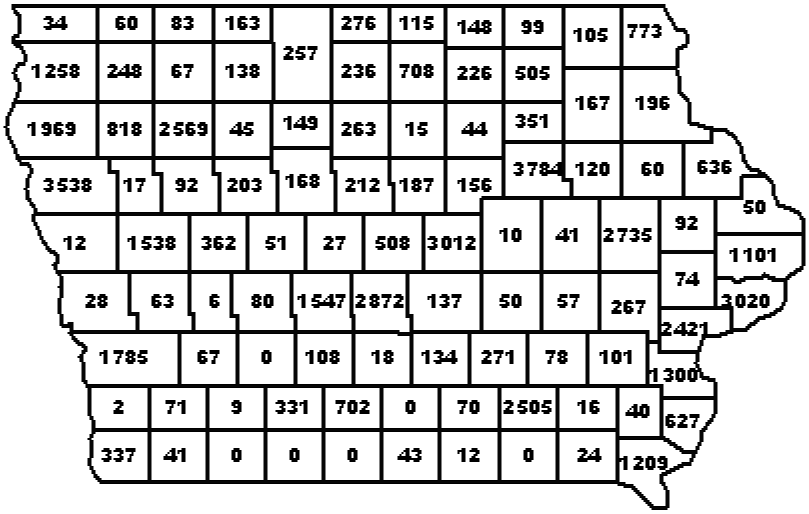


Figure 1.1 – Food processing employees in Iowa

DEFINITION OF FOOD PROCESSING
Food processing is defined as converting edible raw materials into higher value consumer food products. The conversion process utilizes significant amounts of labor, machinery, and energy. In addition, it relies increasingly on scientific knowledge to both improve food quality and safety, and to reduce production costs.

The North American Industry Classification System (NAICS) groups businesses into categories based on their primary activities. NAICS has replaced the older Standard Industrial Classification (SIC) codes to provide a common basis for economic data collection and analysis for the U.S., Canada, and Mexico. Food processing is part of the manufacturing sector: its NAICS classification code is 311. The sub-sectors are:

3111 Animal Food Manufacturing
3112 Grain and Oilseed Milling
3113 Sugar and Confectionery Product Manufacturing
3114 Fruit and Vegetable Preserving and Specialty Food Manufacturing
3115 Dairy Product Manufacturing
3116 Animal Slaughtering and Processing
3117 Seafood Product Preparation and Packaging
3118 Bakeries and Tortilla Manufacturing
3119 Other Food Manufacturing

Beverage manufacturing is classified in NAICS category 312 Beverage and Tobacco Product Manufacturing.

ECONOMIC IMPORTANCE

Food processing is one of the largest and most important of all manufacturing sectors in the U.S. Data from the Advance Report of the 2002 Economic Census show that food manufacturing includes 26,300 individual companies with combined sales exceeding $457 billion, annual payrolls of over $45 million, and a combined workforce of more than 1.5 million employees. Within the manufacturing sector (NAICS Codes 31 through 33) food processing is second in sales, third in workforce size, fourth in number of individual businesses, and fifth in annual payroll. Based on a comparison of the 1997 and 2002 economic census, food processing is the only sector in manufacturing that reported growth in all four categories.

Food processing is a significant component of Iowa’s employment activity with all but five of the 99 counties engaged in some aspect of it (see Fig. 1.1). Fifty-five counties have over 100 workers employed by food processors. According to 2002 data from the Bureau of Economic Analysis, food processing in Iowa contributes $4.3 billion to the Gross State Product (GSP). This is 21% of the manufacturing GSP, making it the largest sector in manufacturing, both in sales volume and number of employees. Currently Iowa has 682 food industry employers with a combined workforce of 51,341 employees.

HISTORY

The development of the food processing industry has been driven by two primary factors: food safety and the need for a longer “shelf life.” The earliest forms of food processing were heat-dried food products. The French, in the 1790s, were the first to record efforts at using heated air to dry food. They were encouraged in their efforts by their emperor, Napoleon Bonaparte, who offered a prize for the development of foods that could be preserved for his army. French chef and candy-maker Nicolas Appert won the prize by cooking and then reheating food in glass bottles sealed with wax corks, and, for this reason, Appert is recognized to be the “father of canning.” The fragile bottles were eventually replaced, beginning in England, with durable metal containers.

The next step in the evolution of food processing occurred in the 1860s when Louis Pasteur discovered that partial sterilization (by heating to a temperature well below that required in canning) of liquids such as milk, orange juice, wine, and beer would destroy disease-causing and other undesirable organisms.

In the early 1900s Clarence Birdseye, an American field naturalist working for the government near the Artic Circle, noticed that freshly caught fish, frozen in snow, retained its fresh qualities after thawing. After years of experimentation, Birdseye developed a process to freeze fish (and, later, other food) between two flat, refrigerated surfaces under pressure. On March 6, 1930, in Springfield, Massachusetts, Birdseye’s company launched the retail frozen foods market with 26 items, including 18 cuts of frozen meat, spinach and peas, a variety of fruits and berries, blue point oysters, and fish fillets.

Modern food processing still involves using energy to raise and/or lower the temperature of a product to make it safer and extend its shelf life. Dehydration is also a common process used to extend shelf life, and it has its own energy requirements. As a result of these advancements, consumers can spend less of their food dollars on basic meat, eggs, and dairy products, which gives them additional resources to invest in value-added products that provide convenience (and quality).

ENERGY CONSUMPTION

Food processing is an energy intensive activity. In 1998, it consumed 7%—more than 213 trillion Btu—of the total electricity used nationwide by the manufacturing sector.

According to the American Council for an Energy Efficient Economy, less than 8% of the energy used by manufacturing is for non-process uses such as facility heating/cooling, lighting, ventilation, etc. Therefore, the main focus of managers who want to reduce energy costs must be on process-related uses.

PURPOSE OF THIS PUBLICATION

The mission of the Iowa Energy Center (IEC) includes striving to improve energy efficiency in all areas of Iowa's energy use. Obviously, industry is a significant consumer of energy, and the IEC has funded the work behind this publication with the intent of improving energy efficiency in Iowa's largest manufacturing sector, food processing.

APPROACH

Energy efficiency can be improved in at least two ways: (1) directly through means that reduce consumption and/or waste at the point of use, or (2) indirectly through means that reduce the required amount of energy per unit of product produced. An example of direct savings would be replacing an oven burner with a more efficient design, thus reducing the natural gas consumed by the oven. An example of indirect savings would be improving the mechanical efficiency of a mixing process by changing the physical shape of the container, the shape of the mixing device, and/or the movement of the two, thereby reducing mixing time for a given volume of product. The energy requirement per unit of output for that process would be reduced. Thus, the energy efficiency would be improved because the ratio of product produced to energy consumed was improved.

This publication will focus primarily, but not exclusively, on the direct means of reducing energy consumption and/or waste at the point of use. It will, however, also present means to indirectly reduce energy requirements through increased efficiencies in processes.

The heart of this publication is the chapter titled Energy Management. The remaining chapters are organized by process type, not by industry sector. Because processes are common to many different sectors, it was believed that the document would be more effective organized in this way.

There are also several appendices that provide information on many existing resources that food processors can use in their efforts to improve energy efficiency.

2. Energy Management

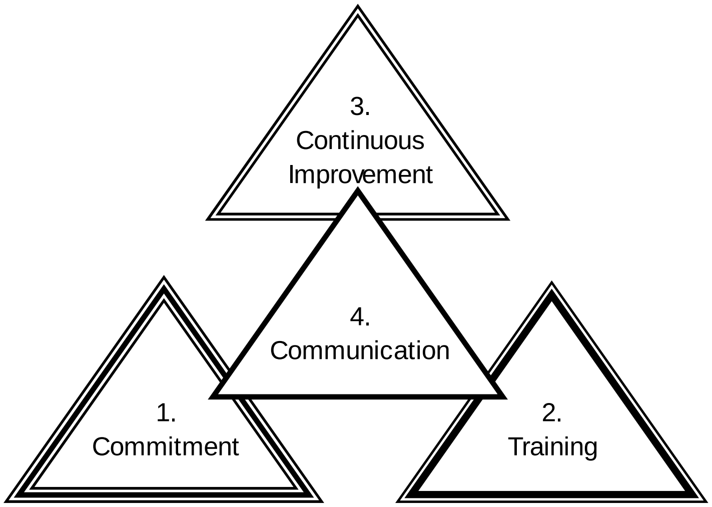


Figure 2.1 – Energy Management diagram

ENERGY SAVINGS

A strategic approach to energy management can result in significant energy savings for all types of businesses, including food processors. The management model, diagrammed in Figure 1.1, requires commitment (1) from leadership, training (2), continuous improvement (3) through strategic goals and action plans, and communication (4). This model draws on ideas from several existing programs, including the “Energy Star”[1] program developed jointly by the U.S. Department of Energy and the Environmental Protection Agency. The Energy Star Program has recently increased its participation in the industrial sector and has over 450 industrial participants including Anheuser-Busch, Ben and Jerry’s, Cargill, McCain Foods, Sargento Foods, and Weaver Potato Chip Company.

DOES EM CONFLICT WITH LEAN, TOTAL QUALITY, SIX SIGMA, ISO, ETC.?

Companies that are using management principles like Lean, Total Quality (TQ), Six Sigma, ISO 9000, and Theory of Constraints to achieve world-class performance may wonder whether an Energy Management (EM) program will work with their current initiatives. The answer, in *all* cases, is a resounding “yes.” EM will complement any initiative, regardless of a company’s place in the process. Whether a company’s just beginning TQ or well into ISO 9000, it will still benefit from a strategic energy management program.

Consider Lean. At least five of the seven forms of waste (and, arguably, all seven) usually involve energy waste. Overproduction obviously wastes energy, as do unnecessary transportation, inappropriate processing, and the production of defective

---

[1] For more specific information on the Energy Star for Industry, refer to http://www.energystar.gov/index.cfm?c=business.bus_index.

products. Waiting can also be a huge waste of energy if the process that is waiting for work-in-process to arrive is a continuous, high consumer of energy such as an oven or a dryer. Clearly, efforts to manage energy are consistent with reducing waste.

Similarly, there are parallels between EM and TQ. Both start with a commitment from the top, are data driven, and involve a cultural change for all of the employees in the organization. TQ provides many tools to make an EM program more effective.

Six Sigma is also data driven and focuses on improving quality of all processes. Similar to TQ, the tools of Six Sigma can and should be used to enhance the quality of an effective EM program.

ISO 9000 and ISO 14000 are also widely used in the food processing industry. These two standards will work with EM to simultaneously build high quality into the EM program and to improve the program as it develops over time.

Theory of Constraints is based on the concept that improving a few capacity constraint resources in a production system will have the greatest impact on the bottom line. In energy intensive industries like food processing, it is often the case that energy-intensive equipment, such as ovens or spiral freezers, are bottlenecks. When such equipment is truly a physical constraint, reducing energy consumption per unit by increasing the flow rate at that piece of equipment will significantly improve bottom line performance.

In summary, an effective EM program will complement current management efforts and will help improve company performance.

MAKE THE COMMITMENT

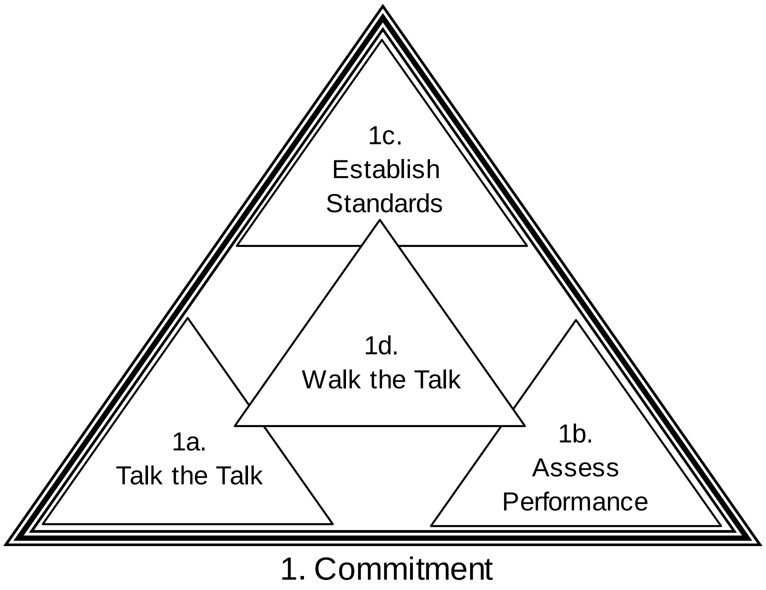


Figure 2.2 – Commitment diagram

Dr. W. Edwards Deming, an Iowa native whom many consider to be the founder of the Total Quality (TQ or TQM) movement, refused to work with an organization unless its top leaders were involved in the improvement process. Commitment starts at the top, he believed. So it is with Energy Management—an effective EM program starts with the support and participation of the company's leaders. So, what constitutes real participation?

Talk the Talk (1a in Figure 2.2)

Company leaders must be strong advocates for an EM program. In addition to supporting a corporate energy policy, they should do the following:

- make EM part of the corporate strategic plan
- tie EM to corporate financial goals
- tie EM to corporate environmental goals

Assess Performance (1b in Figure 2.2)

An old maxim says, "If you don't measure it, you can't manage it." The "it" in this case is energy performance. Once Energy Management is truly on the corporate radar screen, an initial measurement and assessment of energy performance is necessary. It should include the following:

- understanding energy cost structure
- understanding current energy usage and trends

Understanding the Energy Cost Structure

Utility companies generally determine the energy cost structure. Most utilities have multiple rate plans, which can complicate attempts to understand them. Customer service representatives work with businesses to ensure that the most favorable plan has been assigned. An onsite visit from the energy provider is one way to facilitate a discussion on energy needs and cost structures.

Chapter 3 of this publication contains detailed information about the various types of charges and cost structures that may be encountered.

Understanding Current Usage and Trends

Understanding current energy usage and trends goes hand-in-hand with understanding energy cost structures. Usage dictates the choice of rate plan, and the rate plan greatly influences cost savings strategies. As much as feasible, energy usage should be tracked by both:

- end use
- fuel type

End Use

An important step in EM is determining the exact sources of energy consumption. The Centre for the Analysis and Dissemination of Demonstrated Energy Technologies (CADDET) recommends establishing Energy Accountable Centers (EAC)[2] to facilitate this step of the process. These are production areas that are neither too small nor too large, in which energy consumption can be measured and reported independently. (It may be necessary to install meters.) For example, it may be revealing to monitor the energy consumption of a separate building, a central boiler house, or a specific production line.

Many of the details of the end-use patterns can be defined by a technical assessment or energy audit. There are many sources for these audits including private consultants, utility companies, and some government-funded organizations. For a case study of a very successful plant-wide assessment done in Iowa and facilitated by Iowa State University’s Center for Industrial Research and Service (CIRAS), go to the DOE web site listed in the footnote below.[3]

Another valuable resource for energy assessments is the DOE-funded Industrial Assessment Center (IAC). The IAC provides free energy audits to small- and medium-sized facilities. The center that serves Iowa (and some of the area in surrounding states) is located on the Iowa State University campus. For more information about the program and eligibility requirements, check out the web site listed in the footnote below.[4]

---

[2] *Energy Management in Industry, Analyses Series 17*, Centre for the Analysis and Dissemination of Demonstrated Energy Technologies, CADDET, 1995.

[3] *North Star Steel Company: Iowa Mini-Mill Conducts Plant-Wide Energy Assessment Using a Total Assessment Audit,* http://www.oit.doe.gov/bestpractices/factsheets/steel_cs_northstar.pdf.

[4] *Industrial Assessment Center*, http://www.me.iastate.edu/iac/.

Another resource for energy efficiency assistance is CIRAS. A field specialist will visit your site, help you assess your situation, connect you with the appropriate resources, and help you implement an EM program.

Fuel Type

Businesses that use multiple sources of fuel (e.g., electricity, natural gas, oil, and/or steam) are encouraged to keep records of the amount of each fuel type consumed. It can be useful to measure the distribution of major energy forms such as steam in order to know the total amount of steam used to operate a cooker, for example. (Remember, if you don't measure it, you can't manage it.)

Establish Standards (1c in Figure 2.2)

As previously mentioned, Dr. Deming is considered by many to be the "father" of TQM. One of the things that he found most disturbing in management practice was the setting of what he called "arbitrary" numerical goals. "In God we trust; all others bring data," he was fond of saying. The proper approach, according to Deming, is to use data to establish energy standards.

A system of energy accounting is needed in order to collect and track useful data. This involves defining the data to be collected and the measures to be generated. Each company should develop a customized prime measure to measure whether the energy purchased is being productively utilized.

Energy Productivity Index

The energy productivity index is a ratio of energy consumed, usually stated in British thermal units (Btu), to a chosen base unit. This performance measure is very important, so the base unit must be carefully chosen. Possible base units include:

- per square foot of space
- per piece manufactured or shipped
- per pound, gallon, or some other measure of output
- per dollar of sales
- per dollar of "value added"

There are advantages and limitations for each of these possible base units. For example, using square footage makes more sense when HVAC is the primary energy consumer but less sense when process energy consumption is significant. The shortcoming to using dollars of sales is that, over time, the figure is distorted by inflation. Using pounds, gallons, or some other appropriate measure of output/volume that has a logical relationship to energy consumed is often a good approach. It may be advisable to use a monetary unit that's directly related to business performance, like dollars of value added. Using both of these measures will give management two important views: how energy management is performing when measured by cost per unit volume of output, and how energy costs compare to the prices that customers are willing to pay for the value added to the products.

Energy cost index

One additional useful index is the energy cost index. It compares the cost of energy to some base unit (as opposed to the energy consumed). The base unit should be the same unit used for the energy utilization index.

Productivity Standards

Most food processors have standards for judging the performance of their production system over time. Similarly, it is recommended that standards be established for energy usage so that the performance of the EM system can be judged over time. Two basic approaches to establishing standards are discussed in the following paragraphs.

First, engineering data can be used to calculate energy and mass balances and the amount of energy theoretically required at optimal performance for the equipment in use in the plant. While this calculation is useful, the result is often not considered “realistic” or achievable “in the real world.” For this reason, some will reject using this as a standard.

A second method is to compile data on past energy consumption. These data should be segmented by EACs whenever possible. An average consumption over some period of time can be calculated and used as a standard. To be “realistic,” it may be necessary to consider factors such as time of year; the “standard” amount of required energy can vary greatly depending on outside temperature and humidity.

While using an average of past energy consumption has the advantage of providing a better prediction of probable energy consumption in the future, it does not give any indication of how efficiently energy is being used in each EAC. For this purpose, a combination of the two methods may be useful. The calculations based on the engineering data that show theoretical optimal efficiency can be compared with the average (or seasonal average). This will give an idea of the “money on the table,” or theoretical potential savings from improving efficiency.

Organizations may choose to set the standard at the statistical average or at a different point based on the theoretical optimum. In either case, performance can be monitored against the standard and variation can be managed appropriately according to each company’s chosen management approach.

Another possible source for setting a standard is benchmarking. This subject has strong supporters and opponents. To be effective, benchmarking requires enough demographic and quality information about another company to determine whether or not a comparison is appropriate. In other words, the comparison should be apples to apples, not apples to oranges.

It may be safer to benchmark against “best practices.” For example, DOE has developed computer-based tools that allow one company that uses steam to compare itself to another company that also uses steam. These tools can be downloaded free from the Internet at the website in the footnote below.[5]

One of the basic tenets of Lean is “perfection.” Rather than being satisfied with meeting some benchmark, companies are urged to relentlessly pursue perfection or zero waste. Zero waste in energy consumption may be hard to define, unless the calculated theoretical energy balance point mentioned earlier is used. Opponents argue that perfection is not a realistic goal because it is impossible to achieve. On the other hand, advocates stress that it is the pursuit of perfection that forces managers to look for the breakthrough ideas that bring into reach that which was previously thought to be impossible.

Assigning Causes for Variation

Once energy accounting is established and standards are set, management should begin to compare actual performance to the standards. However, these comparisons do not themselves tell what is happening. There must be a thorough understanding of the complete set of measures in order to understand whether a variation is just a “normal” statistical fluctuation or something more significant.

For example, tracking the energy cost index helps management isolate one possible source of variation in the energy productivity index. If energy productivity has degraded in the most recent period of analysis, some, or all, of the drop may be attributable to an increase in energy costs.

Additional information may be gained by tracking the trend of energy cost per Btu. This will help determine whether an increase in the energy cost index is attributable primarily to an increase in the base cost of energy/Btu or an increase in Btus per chosen unit of output.

Following are other common, identifiable sources of variation in energy costs. The time period for all such assignable factors should be noted on the data records.

- seasonal weather changes
- increases in total output
- product mix variations
- physical changes to the system, such as the installation of pollution control devices
- use of an alternative fuel
- pilot programs
- specific conservation efforts

---

[5] *DOE Industrial Technologies Program*, http://www.oit.doe.gov/bestpractices/software_tools.shtml.

Walk the Talk (1d in Figure 2.2)

The central component in the commitment diagram (Figure 2.2) is “Walk the Talk.” Company leaders must commit resources including time, talent, and money on an ongoing basis. Attention at the outset followed in a few months by a total disregard for EM will doom the EM efforts to mediocrity at best, and failure at worst.

Indications that senior leadership has an ongoing commitment to EM include the following:

- A corporate champion is named, and, in larger companies, a team is identified.
- Accountability is clearly established.
- EM is an agenda item at all regular leadership meetings.
- The energy policy is evaluated regularly and updated as needed.
- Adequate budget is provided annually for effective EM.

TRAIN PERSONNEL AT ALL LEVELS

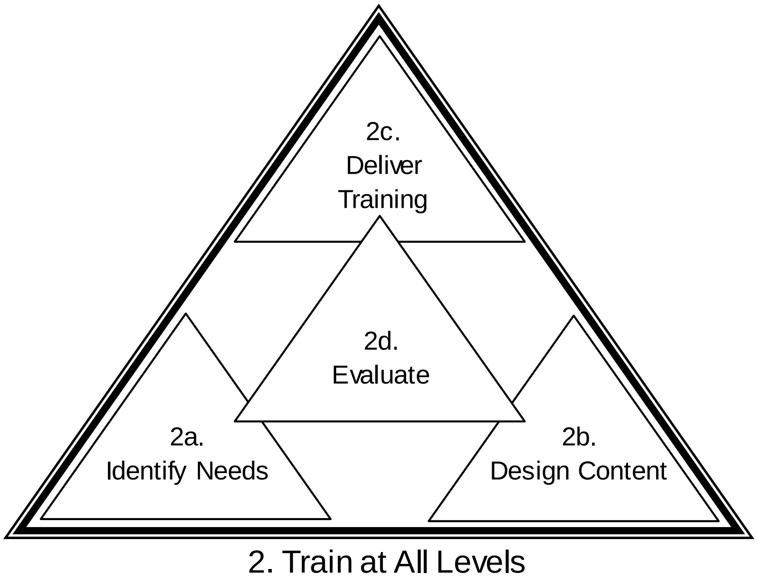


Figure 2.3 – Training diagram

After top leaders in the organization have made the commitment to an EM system and after current energy performance has been assessed and standards are set, it is time to provide training for all company personnel. Sharing information and increasing the knowledge level of employees is a prerequisite to a successful EM system. The opportunity to express personal opinions, ask questions and get answers generally increases the level of engagement for individuals. Feeling engaged is a prerequisite to being motivated.

Identify Needs (2a in Figure 2.3)

Initially, every employee will need some training on topics such as awareness of the corporate energy policy, current usage and trends, basic EM terminology, and energy measures. More specific topics such as “Boiler Management,” or “Assessing Return On Investment in Energy Projects” will be targeted to smaller groups. Be sure to take the time to identify the general and specific needs of the entire staff.

Design Content (2b in Figure 2.3)

In creating content, begin by identifying the specific learning objectives for the targeted individuals. The delivery methods and materials should be chosen to maximize the likelihood of reaching the learning objectives. Training that is specific to a company program will probably have to be developed in house. Training on more standard topics, such as “Boiler Management,” is commercially available from professional sources.

Deliver Training (2c in Figure 2.3)

Planning and good intentions don’t move an EM program forward. A training calendar should be established, and all staff should be scheduled for the training that they need. Follow-through is critical in establishing in the minds of employees that EM is truly important to the organization. Training is best delivered during the staff’s paid time, in a facility that is conducive to learning and that is free of work interruptions.

Evaluate (2d in Figure 2.3)

It is important to determine the effectiveness of the training. Evaluate each learning objective in each session. In addition, it is usually beneficial to ask participants about the following:

- effectiveness of the instructor(s)
- effectiveness of the delivery methods (videos, etc.)
- value of any handout materials
- quality of the training facility

Of course feedback is good, but it is not much good unless it is used! Use the feedback to make changes to training sessions. Re-evaluate and compare scores to determine if the changes are actually improvements.

CONTINUOUS IMPROVEMENT CYCLE

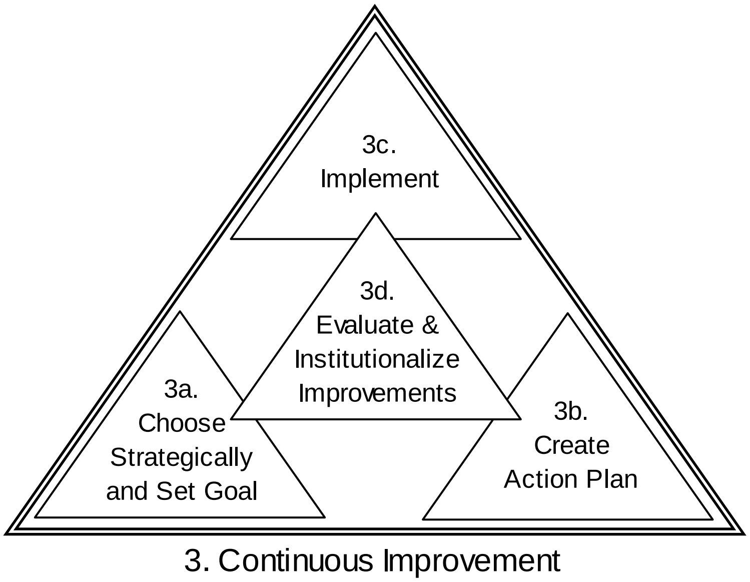


Figure 2.4 – Continuous improvement diagram

Figure 2.2 and Figure 2.3 show the steps required to start an Energy Management initiative. Once begun, the remaining steps can best be characterized as a continuous improvement cycle beginning with Choose Strategically and Set Goal (1), Create Action Plan (2), Implement (3), and Evaluate and Institutionalize Improvements (4). The cycle begins again as the next strategic opportunity is identified and a new goal is set.

Choose Energy Projects Strategically (3a in Figure 2.4)

Strategy is used here to encompass both the global corporate level as well as the EM program.

Consider the global corporate level. First, EM should be part of the corporate strategic plan. Second, EM projects should ultimately contribute to the non-energy-related portions of the corporate strategic plan. The latter may sound difficult at first, but it is actually quite simple. Energy costs are an unavoidable part of doing business, and any money spent on energy cannot be spent on marketing, personnel, etc. Reducing energy costs frees up resources for the non-energy-related components of the corporate strategic plan.

When identifying projects with the potential to save energy, be sure to solicit input from all employees. They frequently have ideas that are easy to implement and provide excellent results.

Now consider choosing projects strategically within the EM program. This requires comparing two important factors of potential energy projects: (1) the potential impact of a successful project to company finances; and (2) the investment required for implementation.

It is a good strategy to start with no- or low-investment projects that have moderate or high potential for savings. A significant portion of the savings generated by these projects should then be budgeted to finance the investment in more costly projects.

Assessing Financial Impact

This can be a very challenging but important component because it is the key to strategic choice. Although the merits of a project may seem clear to those who work in the effected area, it may be difficult to get buy-in from the boss or the financial officer. The challenges can be minimized if the case is presented in financial terms. Three common types of financial analyses are:

- payback period
- rate of return
- total life cycle cost

The *payback-period* analysis is commonly used, in part, because it is simple. To make the calculation, divide the cost of doing the project by the annual savings or return from a successful project. For example, if it would cost $25,000 to implement changes and the annual savings are projected to be $15,000, then the payback period would be 1.67 years (25,000/15,000). Most companies set a maximum that is acceptable for a payback period and reject projects that do not meet the test.

The *rate of return* method involves other factors and more complex concepts such as net present value, interest rates, and depreciation. A detailed explanation of these factors is beyond the scope of this publication. There are resources available to explain these terms and even to help make the calculations. For example, DOE offers several software packages that will take the information and calculate projected savings. These tools are available at the website in the footnote below.[6]

Although the *total life cycle costing* method is a complex way of evaluating projects, it is gaining support as a more accurate picture of long-term impact. Depending on the complexity of the model, total life cycle will consider owning and operating costs as well as such factors as environmental impact and costs, disposal/recycling costs, etc. For projects that may not meet the required investment threshold using other methods, this long-term look at cost may show that it is indeed a wise investment.

No matter what method of financial analysis is used, it is *critical* to carefully account for not only the savings that come directly from a project, but also any measurable “returns” that are caused by the project or made possible because of it. For example, before switching from a blast freezer to a spiral freezer, a food processor can compare the cost of the new equipment to its projected energy savings. If calculations show a payback period of 3.8 years, a 5% rate of return, and an unfavorable total life cycle cost, the project is likely to be rejected. However, if further analysis shows that using the spiral freezer in a continuous flow process would enable the same production crew to increase the daily output by 5%, which, in turn, could be converted to increased sales, the

---

[6] *DOE Industrial Technologies Program*, http://www.oit.doe.gov/bestpractices/software_tools.shtml.

resulting increase in profits may well reduce the true payback period to a matter of months. So, be sure to consider all impacts when making a strategic choice of projects.

Set the Goal (3a in Figure 2.4)

Goal setting can be a controversial subject. Dr. Deming argued vehemently against what he called arbitrary numerical targets. “Substitute leadership,” he said. To arbitrarily say the goal is to “decrease energy costs by 10%” would probably be an example of what Dr. Deming objected to.

However, the Energy Star web site[7] contains some excellent examples of companies that have set high-level goals for their Energy Management efforts. For example, the Food Lion grocery chain has set a long-term goal to “become one of the most efficient grocery stores in the world on a Btu per square foot basis.”

Dr. Deming is also quoted as saying, “In God we trust; all others bring data.” In order to reach their goal, Food Lion must take the actions outlined in this chapter. Steps 2, 3, and 5 are all part of the effort to “bring data.” Food Lion must assess and compare their own performance to their chosen standard of “one of the most energy efficient grocery stores in the world.” They must do some benchmarking to find out what is meant by world-class level of energy consumption for grocery stores. Armed with this information, they can set an informed numeric goal.

Benchmarking will help avoid arbitrariness. Also needed is a systematic approach to continuous improvement. To give people a goal that requires improving the underlying system but not give them the means to change/improve that system would be viewed by Dr. Deming as both arbitrary and de-motivating. The means to improve the system requires the authority that comes from the Commitment (1) of management and the Continuous Improvement (3) cycle in the EM model in Figure 2.1.

Create an Action Plan (3b in Figure 2.4)

The steps needed to achieve improvement should be carefully planned and, at a minimum, should include the following:

- clear statement of desired outcomes and success measures
- list of resources that are and are not available
- sequential list of steps involved
- list of key milestones or intermediate indicators of success
- expected completion date
- clear explanation of reporting requirements (frequency and scope)
- rewards if successful (if applicable)

Be sure to consider the potential negative impacts on product flow and peak energy demand. It is usually advisable to test proposed changes at the pilot level, if possible. For

---

[7] Energy Star®: http://www.energystar.gov/index.cfm?c=performance_goals.determine_scope#success1.

example, if you have four air compressors, plan to make the changes on one and measure the impact.

Implement the Plan (3c in Figure 2.4)

Follow-through is the key to success. Execute the plan step by step. Monitor progress regularly. If progress is made, implementation should continue. Or, if the evaluation indicates a problem, adjustments should be made to the action plan.

Evaluate and Institutionalize Improvements (3d in Figure 2.4)

Evaluate the success of implementation against the goal established at the outset. If the project was at the pilot level and the implementation was successful, the changes should be institutionalized and implemented across the larger system. This may need to be done in phases, depending on the number of pieces of equipment and the capital costs involved. Data collected during the pilot phase should make the computation of financial return easier and justify the additional investment.

Continue the Cycle

As a project is completed, it is time to begin the next pass through the continuous improvement cycle. Go back to step 1: strategic selection of the next project and setting of the goal.

COMMUNICATION

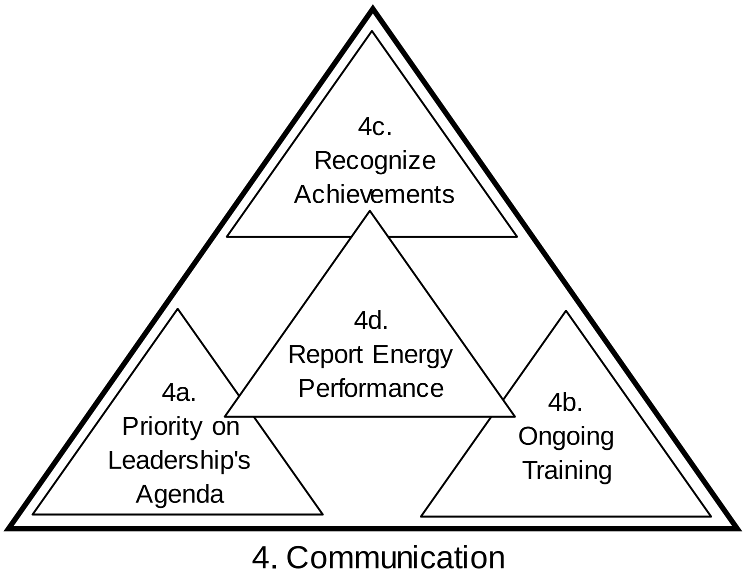


Figure 2.5 – Communication diagram

The centerpiece of the EM model in Figure 2.1 is communication. It is the lifeblood of a successful EM initiative. If Energy Management is not a regular topic of discussion in the company, it will soon be labeled as the latest “flavor of the month.”

EM is a Priority Item on Leadership’s Agenda (4a in Figure 2.5)

The commitment section pointed out that success starts at the top, and it must stay there. Energy should remain prominently on the “radar screen” of company leaders. Remember Dr. Deming’s advice to “bring data.” Company leaders rightfully expect and need the data that will help them make better decisions.

Ongoing Training (4b in Figure 2.5)

Just as management commitment must be ongoing, training must continue over time. The training mix will change as fewer hours are spent on general awareness and terminology, and more time is spent in specific and often technical training. Remember to adequately train new employees as they enter the system.

Recognize/Celebrate Achievements (4c in Figure 2.5)

Recognizing and celebrating the achievements of the EM initiative will bolster employee morale and continue motivation. Employees need to see that their efforts are appreciated and that they make a difference! In its comprehensive communications kit, Energy Star notes that “Communicating your achievements is important because it can motivate employees, enhance customer loyalty, demonstrate your corporate responsibility, build a broad base of support for your energy efficiency initiatives, and make a lasting impact on the environment."[8]

Report Energy Performance (4d in Figure 2.5)

The centerpiece of communication is reporting energy performance. Everyone in the organization should be continuously aware of the current facts and figures on energy performance. Communicate regularly using a standard, easy-to-understand, and accessible format.

Provide the appropriate information in the most understandable format to each level throughout the company. For example, senior management will probably require different information in a different format than will the engineers in the steam room.

Information on energy performance should also be shared with those responsible for planning training. This will help them identify what training is needed during the ongoing process.

---

[8] *Energy Star: Business Improvement*, http://www.energystar.gov/index.cfm?c=ck.ck_communications_kit.

RESOURCES

Printed Material

Caffall, C., Learning from Experiences with Energy Management in Industry, CADDET, Sittard, Netherlands, 1995.

Capehart, T., Kennedy, Guide to Energy Management, Fairmont Press, Lilburn, GA, 2000.

Mull, T.E., Practical Guide to Energy Management for Facilities Engineers and Managers, ASME, NY, 2001.

Thumann, A., Handbook of Energy Audits, Fifth Edition, The Fairmont Press, Inc., 2001.

Wulfinghoff, D.R., Energy Efficiency Manual, Energy Institute, MD, 1999.

On-Line Tools

U.S. Department of Energy

DOE Best Practices in Energy Management: http://www.oit.doe.gov/bestpractices/

DOE Plant Wide Assessments: http://www.oit.doe.gov/bestpractices/assessments.shtml

Energy Matters: www.oit.doe.gov/bestpractices/energymatters/energy_matters.shtml

Software Tools: www.oit.doe.gov/bestpractices/software_tools.shtml

- Process Heating Assessment and Survey Tool (PHAST)
- Steam System Scoping Tool
- Steam System Assessment Tool (SSAT)
- 3E Plus – Insulation Thickness Computer Program

Energy Star for Manufacturers: http://www.energystar.gov/index.cfm?c=manuf_res.pt_manuf

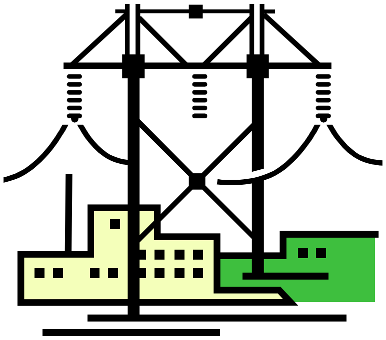
Organizations

Association of Energy Engineers: www.aeecenter.org

Iowa State University Industrial Assessment Center (IAC): (515) 294-3080 or www.me.iastate.edu/iac

United Kingdom Energy Efficiency: www.etsu.com

3. Energy Cost Structure



Most utilities offer commercial customers different billing options depending on the level of energy used by the customer as well as the variation in the usage pattern. To determine the best billing method for a specific user, a customer service representative reviews the last 12 months of energy use and considers significant changes, if any, to future usage patterns.

A brief explanation of the common factors included in a commercial billing plan follows.

ELECTRICAL (PEAK) DEMAND CHARGES

Electrical demand is measured in kilowatts (kW). Peak demand is very important when the utility company calculates electrical bills. The utility is concerned about peak demand because the size of the equipment it uses to generate and transmit electricity must be sufficient to handle the peak demand of its customers. Therefore, a portion of the charges from many utilities is based on peak demand. Peak demand charges are based on the highest average kW demand during any one-demand interval (usually a 15- or 30-minute period) of the billing cycle. Billing rates for peak demand vary greatly by billing plan.

Ratchet Clause

Sometimes peak demand charges are based on the highest average peak demand in one demand interval during the past year (or during the "summer" months). This is known as a "ratchet" clause. In such cases, electric charges will be impacted every month for a single 15-minute period of high demand during the past year (or the last "summer" month period).

MANAGING PEAK DEMAND

Although it may not always be easy, there are ways to manage peak demand. Strategies include:

- sequenced start-up
- staggered or deferred usage
- sheddable loads
- permanent reduction of on-going loads

As the term implies, “sequenced start-up” means starting equipment at different times at the beginning of a shift. If multiple pieces of equipment require less than “full time” operation (i.e., less than eight hours in a single shift or 24 hours in a three-shift operation), it may be feasible to stagger their use. In multiple shift operations, it may be possible to reduce peak demand by performing energy intensive processes on different shifts. For example, using dryers on one shift and cookers on another will reduce the peak load (compared to running both operations at the same time) and, therefore, will reduce energy costs.

Categorizing demand as either essential or non-essential can also lead to energy savings. When discontinued for short periods of time, non-essential or “sheddable” loads lower energy usage without reducing productivity or comfort. Some examples include electric heaters, air conditioners, pumps, snow-melting equipment, compressors, and water heaters.[9] It is possible to install monitoring equipment that alerts the energy manager when demand reaches a predetermined range, so that he or she can decide whether or not to begin shedding loads. Shutting down or restricting the sheddable loads once a certain demand in kW is reached can significantly reduce peak demand charges.

Any ongoing load that is reduced or eliminated during the peak will cut total usage and also reduce the peak. The good example here is switching from traditional overhead lighting to newer cost-effective, energy-efficient lighting.

ELECTRICAL ENERGY (USAGE) CHARGES

The kilowatt-hour (kWh) is the basic unit of electrical power usage/consumption. Most utilities offer industrial customers a lower price per kWh as consumption increases. The price typically changes at fixed levels of usage, so that there are two or more usage *tiers*. For example, in a three-tier system, the first 250 kWh may be billed at one rate, the next 750 kWh at a somewhat lower rate, and any usage in excess of 1,000 kWh would be billed at an even lower rate.

Usage tiers may change depending on the time of year. In the summer there may be only one tier while the winter months may have multiple tiers. The cost of the energy in each tier is also likely to change depending on the time of year. There may also be a charge depending on the time of day the energy is used. For example, each kWh consumed during “on peak” hours will often have a higher charge than each kWh consumed during “off peak” hours.

One method of billing actually combines peak demand with energy usage. In this method, the number of hours in each tier is multiplied by the peak demand to determine the number of kilowatt hours charged at the rate for that tier. Since this type of billing also contains a separate demand charge, reducing peak demand can significantly reduce the total cost of electricity by thousands of dollars per month.

---

[9] *Handbook of Energy Engineering, Fifth Edition*, Thumann and Hehta, The Fairmont Press, Inc. 2001.

REACTIVE DEMAND CHARGES

Commercial customers like food processors use a lot of equipment (induction motors, transformers, florescent lights, induction heating devices, etc.) that requires magnetizing current that is measured in “kilovolt-amperes reactive” (kVAR). Kilowatts (kW) is a measure of the work-producing current in the circuit. Total current, which is impacted by the combination of magnetizing current and work-producing current, is measured in kilovolt-amperes (kVA). The *power factor* is the ratio of kW to kVA. When the magnetizing current is zero, kW is equal to kVA and the power factor is 1.0. This is good for the utility and there would be no additional charges on the electric bill.

In circuits that use magnetizing current, the total current rises and the power factor drops below 1.0. A low power factor, 0.6 for example, means that the utility has provided a large quantity of reactive current (kVAR) that would not be covered by a charge for only the kilowatts delivered. For this reason, utilities often include some sort of reactive demand charge on the electric bill. These charges can be very significant if the power factor is very low; however, this is typically not the case in Iowa.

The good news is that reactive demand charges can always be dramatically reduced, and often even eliminated. Capacitors can be installed that will provide the needed reactive current, thereby bringing the power factor close to 1.0. Review of at least one year’s data on the maximum demand, power factor, typical energy usage, and reactive demand charges will help users calculate the amount of capacitance that must be installed to raise the power factor to an acceptable level. For help, consult with the electric utility or the Industrial Assessment Center[10].

INCENTIVES AND REBATES

A variety of incentives and rebates on energy-efficient equipment are offered to commercial customers. A partial list follows; updated lists are available from most utilities.

- fluorescent T-8 and T-5 lighting
- reduced wattage metal halide lamps
- chillers
- ground source heat pumps
- high-efficiency natural gas boilers
- motors and variable speed drives
- compressed air system equipment

In addition, customized or special projects that save energy may also be considered for incentives or rebates.

The state of Iowa exempts a certain amount of electricity costs for industrial production loads from sales tax. A certificate of verification is required and must be renewed every

---

[10] The Industrial Assessment Center, funded by the U.S. Department of Energy that serves Iowa is located at Iowa State University. Their web site is http://www.me.iastate.edu/iac/, or call (515) 294-3080.

three years. Once certified, commercial customers who have not previously been exempted may apply for a refund of overpaid taxes from previous years.

4. Mixing

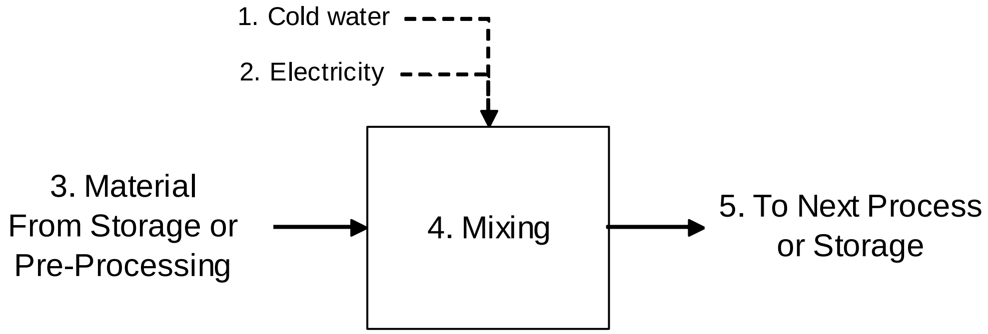


Figure 4.1 – Mixing system diagram

MIXING SYSTEM OVERVIEW (REFER TO FIGURE 4.1 ABOVE)

Mixing is probably the most universally used process in the food processing industry. It can involve solids, liquids, or gases, or any combination of the three. The ultimate goal may be to completely mix the ingredients to obtain a homogenous mix, such as in many cake mixes, or to mix suspended ingredients, such as in many salad dressings.

In general, the conversion of ingredients will result in a final mixture that is one of the following:

- a liquid
- a dry powder
- a thick paste

Proper flow of material in the mixer is important to ensure the quality of the end product. Insufficient flow throughout the container causes pockets of unprocessed or incompletely processed materials that will settle to the bottom or float on top of the mixture. Also, insufficient flow can burn some of the mixture if heat is not dissipated properly; overshear of sensitive ingredients is another possibility.

Liquid mixers that use some sort of propeller or paddle are very common. To provide adequate flow, the rotor is often offset or some sort of baffling is used.

Ribbon blenders using twin-screws, and double-cone mixers are commonly used with dry powders. They provide vigorous intermixing of the ingredients.

Thick pastes are mixed by heavy equipment that often uses contra-rotation to shear the mixture. In some cases, this process can generate a significant amount of heat. To avoid damaging the product, mixing vessels may be wrapped in cooling jackets.

The amount of energy consumed may not be directly related to the degree of mixing that takes place because many foods change in viscosity as they are mixed. In some cases, such as the high-speed mixing of flour dough, the longer the mixture is worked, the greater the energy required to operate the mixer. This is due to the fact that flour components oxidize when mixed in air, requiring greater shearing forces and, therefore, more power to operate the mixer. However, in other cases shear forces decrease as the product is mixed, such as in making ketchup.

Mixing is easiest when components are of similar density and used in roughly equal proportions. When proportions vary greatly, like mixing a small amount of vitamins into cereal, it is usually best to mix the product in stages.

ENERGY EFFICIENCY

Electric motors are commonly used to provide the energy input for mixers. Energy consumption can be quite high, especially when mixing thick pastes that tend to revert to their original shape, like flour dough. It is possible to expend large amounts of energy without doing much mixing. With well-designed equipment, however, energy consumed does correlate to the degree of mixing taking place. This relationship can be determined through experimentation, and in some instances consumption of electricity is closely monitored and used to determine when sufficient mixing has occurred.

As mentioned, mixing thick pastes can generate significant heat. To avoid damaging the product, cold water is sometimes circulated through a jacket around the mixing bowl to remove excess heat.

Some ingredients and mixtures require temperature monitoring and control. For example, some liquids stored in bulk will be pumped through heated lines to maintain the proper viscosity for reliable delivery and mixing. A common method for warming the lines is to pump warmed water through a jacketed line; the temperature in the water jacket is monitored and controlled to maintain the needed viscosity of the liquid ingredient.

WEIGHING

Frequently, ingredients need to be weighed before they are mixed. Increasingly, this part of the process is being done automatically on continuous feed lines. Electric motors, a series of electronically controlled devices, and a conveyor/auger system work together to accurately weigh ingredients, delivering precise amounts into the mix when required. These systems generally do not consume large amounts of energy.

BEST PRACTICES

Electric motors are the primary source of energy used to power mixers. The size of the motor should be directly related to the load required by the mixer. Avoid over or under sizing. When a mixer is used for ingredients that have significantly different load requirements, consider motor speed controls.

For best practices on size selection, speed controls, and maintenance of electric motors, refer to the Appendix: Motors and Pump/Fans.

The noise generated by some mixers may be intense. In these cases, the best practice is to either isolate the mixer or use excellent ear protection.

PRODUCTIVITY FACTORS

In recent years, food processors have been pressured to increase the output or “flow” throughout the entire operation. As manufacturers take steps to reduce waste, they realize that what seems like a small, insignificant improvement in isolation amounts to a very profitable savings when extrapolated over an entire year.

In order to convert an increase in flow at a particular point in the system into profit dollars, that “local” improvement must result in an actual increase in the output of product that is immediately used to fill customer orders. In other words, there will *not* be an increase in profits if the increased flow at this point in the system just means the product waits longer in another queue or sits in a warehouse. The term commonly used today to describe a resource that limits the output of the system is “bottleneck.” If mixing is the most restrictive bottleneck in the system, the following factors should be considered to increase flow and, therefore, profits (over and above the financial gains from reduced energy costs). Note that lack of orders may be the true “bottleneck” of the system. Increasing output of product that will not sell, i.e., overproducing, is a major waste!

- Mixing time—Better-designed equipment that provides the required flow and shear in a shorter amount of time will increase productivity by making it possible to run more batches every day.
- Discharge time—The ability to empty the contents faster adds capacity for more batches every day.
- Clean-up time —Factors that shorten clean-up time (e.g., discharge completeness and surface finish) add capacity for more batches and reduce the likelihood of cross-contamination between batches.
- Variable speed drives—The ability to change the speed of the mixer allows more intense mixing at high speeds, while still being able to run lower speeds for other ingredients[11].

---

[11] Ross Online: http://www.ribbonblenders.com/operation.asp.

RESOURCES

Printed Material

Singh, R.P. and Heldman, D.R., Introduction to Food Engineering, Academic Press, 3rd ed., 2001.

Wulfinghoff, D.R., Energy Efficiency Manual, Energy Institute, MD, 1999.

On-Line Tools

Earle, R.L., Unit Operations in Food Processing: http://www.nzifst.org.nz/unitoperations/index.htm

Energy Manager Training: http://www.energymanagertraining.com/new_index.php

Online Chemical Engineering Information, Pinch Technology: Basics for Beginners: www.cheresources.com/pinchtech1.shtml.

Singh, Paul, Teaching Resources: Animation: http://www.rpaulsingh.com/animated%20figures/animationlist.htm

Organizations

Association of Energy Engineers: www.aeecenter.org

International Energy Agency: www.iea.org

Iowa Energy Center: www.energy.iastate.edu

Iowa State University Industrial Assessment Center (IAC): (515) 294-3080 or www.me.iastate.edu/iac

5. Separation

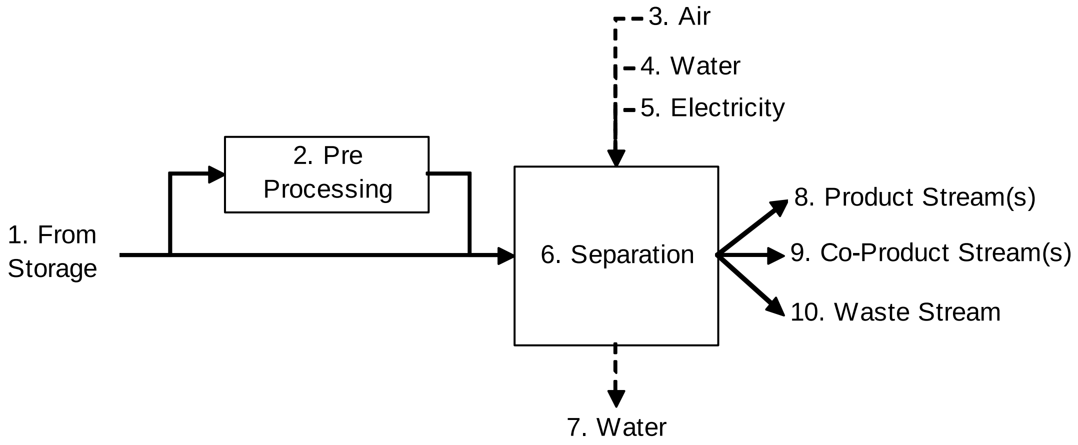


Figure 5.1 – Separation system diagram

SEPARATION SYSTEM OVERVIEW (REFER TO FIGURE 5.1 ABOVE)
Separation is simply the process of dividing material into its component parts. This may involve separating a solid from a solid, such as removing nuts from their shells; separating a solid from a liquid, such as removing pulp from juice; removing a liquid from a solid, such as squeezing oil from a kernel of corn; removing a liquid from a liquid, such as separating fat from milk; or removing gas from a solid or liquid, such as vacuum canning.

Separation is a process that is arguably more important to the bottom line of food processors today than any other. This claim is based on three factors:

- multiple value streams from one raw material
- improved yields
- energy savings in downstream processes

Separation adds value to the extracted product, its residue, or both. As the United States seeks to reduce its reliance on fossil fuels, the economic importance of effective separation has never been greater. Petroleum is used to produce a large number of industrial products from fabrics to paints to chemicals to medicines. Nearly all of these goods can be produced with biobased materials. A cluster of biobased manufacturers, referred to as a biorefinery, can produce food, enzymes, medicines, and fuel in one complex. What was previously considered waste now can be separated and processed, and used to make a variety of products. This can significant increase profitability.

As shown in Figure 1.1, material may come directly from storage (1), or it may undergo some pre-processing (2), such as size reduction, before entering the separation process (3). It is possible to separate foods based on many physical properties including size, shape, density, viscosity, solubility, and thermal, diffusional, and optical properties. For this reason, the food processing industry uses many different methods to separate materials. Several are described below.

Sedimentation relies on gravity to separate solids from fluids. Large pieces of equipment are needed to handle economic volumes and still allow sufficient time for proper settling. In continuous flow operations, flow rates are usually low to avoid agitating the sediment; the process must include a way to remove sediment without re-contaminating the fluid.

In many cases, gravitational sedimentation is too slow. For example, if whole milk is left to stand, the cream will rise to the top and eventually there will be a clean separation from the skim milk. However, this process takes many hours to complete, which makes it too costly.

Centrifugal sedimentation accelerates the separation rate. Many different designs are available for applications from milk separation to removing solids from beverages and dewatering sugar crystals. The most common application of centrifugal sedimentation in the food industry is probably the use of cyclones.

Flotation is used in applications where the particles to be removed adhere to the surface of a bubble. The bubble rises to the surface and the froth, which contains the target particles, is easily skimmed. This is commonly used to remove fat from wastewater.

Filtration uses a porous medium to prevent the passage of particles above a certain size. The objective is either to remove a relatively small amount of small solids from a valuable fluid or to separate slurry into a solid cake and a liquid. In the latter case, the cake, the liquid, or both could be the desired product. Examples include filtrations of juices to remove high levels of insoluble solids and yeast recovery after fermentation in the brewing industry.

Membrane separations are used when the size of the target particles is too small for conventional filters. Terms such as hyperfiltration (reverse osmosis), ultrafiltration, microfiltration, and nanofiltration are used to describe methods of membrane separation. These are used in water treatment and milk processing as well as to create high concentrations of fruit juices. Instant coffee concentration also makes use of membrane technology because it has been proven to give better retention of aromatics.

Screening is used to separate material into various particle sizes. A single screen or sieve may be used to separate material into two streams, or a series of screens may classify the material into multiple sizes. The time required to separate by screening is affected by size of the particles, size distribution, density, intensity of the vibration, and humidity of the air. Screening is used, for example, to separate the various fractions of flour.

Air classification may be the original separation process. The separation of chaff from wheat by winnowing is a simple method of air classification. When performed in an enclosed chamber, lengthening the chamber, including collision surfaces, or adding centrifugal force can increase separation effectiveness. “Cut size” indicates the desired point of separation. Ideally, all particles smaller than the cut size end up in the fine stream, and all particles larger than the cut size end up in the coarse stream. The extent to which each stream is "pure" determines the efficiency of the process. Air classification is used in the cereal and legume industries to separate components (particularly proteins).

Electrostatic sorting is used to clean some raw materials. The solids are fed into a rotating drum that is electrically charged, or grounded, and particles in the air that have the opposite charge are attracted to the drum and scraped away. Humidity must be controlled for this process to be effective. Electrostatic sorting is used in the tea and cereal sectors to remove dirt or unwanted residues.

Reflectance refers to the ability to reflect light off the product. This enables optical sensors to detect color differences on the surface of products. Applications include sorting ripe produce from green fruit and vegetables and then rejecting discolored or spoiled product.

Expression uses mechanical forces to separate liquids, such as oil or juice, from within the cellular structure of plant material. Belts, rollers, or rotating screws provide the force to express fruit juices, cane sugar, and oil from seeds.

Extraction is used for similar purposes as expression, but it relies on the different solubility of the components to be separated. A liquid is thoroughly mixed with the components and then the streams are separated. Coffee and sugar are commonly extracted from the bean or cane/beet, respectively. "Many oil extraction processes employ expression, followed by solvent extraction, to obtain a high recovery of oil."[12]

Crystallization separates a solid component from a liquid solution. "Soluble components are removed from solution by adjusting the conditions so that the solution becomes supersaturated and excess solute crystallizes out in a pure form. This is generally accomplished by lowering the temperature or by concentration of the solution, in each case to form a supersaturated solution from which crystallization can occur."[13]

Dehulling and *peeling* are separation processes that remove the outer covering from the raw material. Dehulling is usually accomplished by milling, and efficiencies can range from 85 to 95%.[14] Peeling is done by abrasive, chemical, or thermal mechanisms. All present some risk of damaging the product.

Separation will create a product stream (8) or product streams, and possibly a co-product stream (9) or co-product streams, and possibly a waste stream (10). The co-products may or may not be used in the food industry and may or may not be further processed in-house. The co-products may be packaged and shipped or, in the case of a biorefinery, simply piped to an adjacent processing facility.

---

[12] *Separation Processes In the Food and Biotechnology Industries*, Edited by Grandison and Lewis, Woodhead Publishing Limited, Cambridge England, 1996.

[13] *Unit Operations in Food Processing*, R.L. Earle, The New Zealand Institute of Food Science and Technology, http://www.nzifst.org.nz/unitoperations/index.htm.

[14] *Separation Processes In the Food and Biotechnology Industries*, Edited by Grandison and Lewis, Woodhead Publishing Limited, Cambridge England, 1996.

ENERGY EFFICIENCY

In most cases, the separation process itself is not energy intensive. *Electric motors* are widely used to power conveyor belts, rotating drums, fans, screw presses, vibrators, scrapers, etc. Information on them and their energy efficiency is contained in the Appendix. *Pumps* are also used in separation processes and are discussed in the same Appendix.

Process heat is used in many separation processes. In general, heat increases the efficiency of the separation. “However, there are limitations with biological materials: higher temperatures increase degradation reactions, causing color and flavor changes, enzyme inactivation, protein denaturation, loss of functionality, and a reduction in nutritional value. Safety issues with respect to microbial growth may also need to be considered.”[15] Factors effecting energy efficiency in the generation of process heat are covered in the process heat chapter.

PRODUCTIVITY

The purity that is achieved during the separation process affects both yield and energy productivity. Yield, the amount of usable product after separation compared to the total amount in the raw material, has obvious impact on the productivity of the operation. As yield increases, so does productivity and profitability.

In addition, the yield and purity of the extracted product have a significant impact on the energy required for downstream processing such as drying. This, in turn, increases the energy efficiency as the total amount of product made per unit of energy increases. Thus the true cost of production decreases.

---

[15] *Separation Processes In the Food and Biotechnology Industries*, Edited by Grandison and Lewis, Woodhead Publishing Limited, Cambridge England, 1996.

RESOURCES

Printed Material

Grandison, A.S. and Lewis, M.J. eds., Separation Processes In the Food and Biotechnology Industries, Woodhead Publishing Limited, Cambridge England, 1996.

Perry, R.H., Green, D.W., and Maloney, J.O. eds., Perry's Chemical Engineers' Handbook, Seventh Edition, McGraw Hill, 1997.

On-Line Tools

Earle, R.L., Unit Operations in Food Processing: http://www.nzifst.org.nz/unitoperations/index.htm

Organizations

Association of Energy Engineers: www.aeecenter.org

International Energy Agency: www.iea.org

Iowa Energy Center: www.energy.iastate.edu

Iowa State University Industrial Assessment Center (IAC): (515) 294-3080 or www.me.iastate.edu/iac

6. Drying

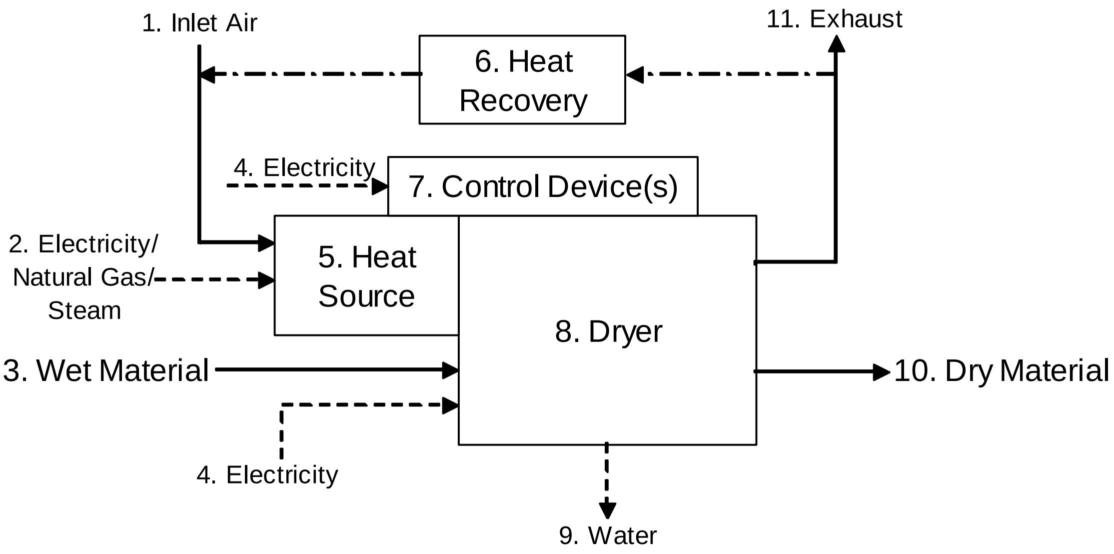


Figure 6.1 – Drying system diagram

Drying is the process of removing water or some other solvent from a solid by evaporation. It is an effective way to extend the life of foodstuff because the microorganisms and enzymes that reduce food quality over time require a sufficient amount of water to exist.

DRYING SYSTEM OVERVIEW (REFER TO FIGURE 6.1 ABOVE)

Several methods of drying are used in food processing including convection, conduction, and direct heating. The most common method is convection, which uses a heat source (5) to raise the temperature of the inlet air (1), which is then forced through a dryer (8). Water and other solvents are removed as the wet material (3) moves through the dryer (9). Dry material (10) and exhaust (11) are expelled. The exhaust not only contains water vapor, but it usually has a significant amount of heat that was not used inside the dryer. Many dryers are fitted with some sort of heat recovery (6) system to recapture as much of this energy as feasible. In many dryers, a control device (7) is used to improve energy efficiency and product quality.

Direct heating methods are used in some dryer designs to improve energy efficiency. The heating medium is eliminated, and induction, infrared, microwaves, or radio frequency waves are used to heat the wet material.

A variety of dryers are used in the food processing industry. A brief explanation of the more common types follows.

Industrial Dryer Types

Rotary dryers are inclined a few degrees and rotate slowly, typically 5-20 rpm. Product moves through the dryer continuously, and hot air is circulated sometimes in the same direction and sometimes in the opposite direction of the product flow. Rotary dryers vary in length from a few feet to over 300 feet.

Spray dryers have a cylindrical or conical vertical chamber into which liquid or slurry is sprayed. As liquid food droplets circulate, the hot air moving through the chamber evaporates the water; a cyclone is used to separate solids, typically with a moisture content less than 5%,[16] from exhaust air.

Band dryers use a perforated metal conveyor to transport wet foodstuff. Hot air is then circulated through the conveyor and the moist material to remove water. Band dryers run continuously and are well suited to products that require gentle handling.

Tray dryers usually operate in batch mode using shelves to hold product and circulating air over the material. Designs range from a simple oven to a rotating conformation of stacked trays. The latter design makes continuous feeding possible as the material enters on the top tray and is then automatically scraped onto successively lower trays as more and more moisture is removed until it leaves the bottom tray sufficiently dry.

Tunnel dryers convey heated air and a series of trays containing wet material through a tunnel. The sides of the tunnel may also be heated to enhance drying.

Fluidized bed dryers combine a perforated plate with regulated air flow rates such that the solid particles become suspended about the plate. These dryers can be operated in batch or continuous flow mode.

Drum dryers use conduction heating. Wet material is dropped onto one or more heated drums. The water evaporates, and the dry material is scraped off with a knife. This can be done in a vacuum chamber.

Pneumatic dryers use a fast-moving stream of air to convey the material up through the chamber. A cyclone at the top allows the dried material to be collected.

Freeze drying is one of the oldest of all drying methods. Ancient Peruvian Incas stored potatoes and other foodstuffs high in the mountains during the winter. The cold temperatures froze the food and the water inside slowly evaporated under the low air pressure of the high altitude.[17] Today, material is first frozen and then placed in a vacuum. This makes it possible to vaporize the frozen water without going through the liquid phase; this is known as sublimation. Heat is applied to accelerate the sublimation process, and, finally, condensers remove the vaporized water from the vacuum chamber.

---

[16] *Introduction to Food Engineering, 3rd Ed.*, by Singh and Heldman, p. 567, Academic Press, San Diego, CA, 2001.

[17] *Freeze-Drying & Freeze-Dried Food* by Mary Bellis, http://www.culinary-cooking-schools-institutes.com/article_freezedried.html, 2003.

ENERGY EFFICIENCY

When considering opportunities for saving energy, it is necessary to view the system holistically, from energy source to exhaust gas recirculation. Potential energy savings must be weighed against other factors including capital expenditure, safety, emissions, and product quality.

Mechanical Dewatering

One effective way to reduce the energy required for the drying process is to use mechanical means whenever possible to reduce the water content prior to any thermal drying. Methods of mechanical dewatering include filtration, centrifugal force, gravity, high velocity air, or compression to force water from the material. Means of compression include presses, rollers, and belts that squeeze water out of the material.

The effectiveness of these methods is limited, and additional thermal drying is usually required. However, the energy used in mechanical dewatering is only 1% of the energy used to evaporate the same quantity of water.

Direct Heating

Direct heating is not feasible in some food processing applications and is often not an economical retrofit option. However, when applicable, direct heating provides significant energy savings because it eliminates the inefficiency of transferring heat to air and from the air to the wet material. The energy efficiency of direct heating is about 90%, compared to the typical 50-60% for a conventional steam-raising boiler and associated distribution system.[18]

Control

Dryers have a number of inputs that, if properly controlled, will result in a cost-effective product that is of acceptable quality. Poorly controlled dryers waste energy both directly by consuming more energy than necessary and indirectly by yielding a product that doesn’t meet specifications and must be discarded.

Dryer inputs fit in two categories: those that can be manipulated (e.g., valve, damper, and burner settings, fan speeds, and belt feed rates) and those that are not easily manipulated but that can greatly disturb components of the process (e.g., ambient air temperature and humidity, feedstock composition, and moisture content).

“The aim of a control system is to maintain the values of the outputs, i.e., quality and cost, at as near to their desired values as possible by changing the manipulable inputs so as to compensate for fluctuations in the values of the non-manipulable [sic] inputs.”[19]

---

[18] *Learning from Experiences with Industrial Drying Technologies*, CADDET Energy Efficiency Analysis Series No. 12, p. 32, CADDET, Sittard, Netherlands, 1994.

[19] *Learning from Experiences with Industrial Drying Technologies*, CADDET Energy Efficiency Analysis Series No. 12, p. 83, CADDET, Sittard, Netherlands, 1994.

Feedback controllers monitor the output, often outlet air temperature and humidity, and adjust manipulatable inputs like fan speed and/or feed rate. The limitation of such a system is that, in many cases, there is a significant lag between when the manipulatable inputs are adjusted and the corresponding changes affect the outputs. During the lag time, significant amounts of out-of-specification product can be produced.

Feedforward controllers monitor “disturbance” inputs like ambient air temperature and humidity and/or product moisture content and adjust the manipulatable inputs accordingly. The challenge with these systems is the need for a mathematical model that accurately predicts the effects of changes to the inputs on the final outputs. Since an accurate model does not always exist, a combination of feedback and feedforward control is used in some cases.

The economic payback of improving control systems depends on the complexity of the system and expense of new instrumentation, if any. In general, the higher the system’s energy bill, the shorter the payback period.

Heat Recovery

Hot air moving through a dryer usually cannot become fully saturated. This is not due to poor design but rather to the rapid drying times in a commercial operation. Equilibrium humidity is the point at which water will not transfer between air and wet material. If the actual humidity of the dryer’s exhaust air is below the equilibrium humidity, the unused potential to absorb more moisture is wasted. Consider the following from the Center for Analysis and Dissemination of Demonstrated Energy Technologies:

> “For example, if the equilibrium humidity is 0.1 kg(water vapor)/kg(dry air), but the actual humidity of the exhaust air is 0.02 kg(water vapor)/kg(dry air) then, for a flow rate of 50 kg(dry air)/s, the same rate of water removal could theoretically be achieved using a flow rate of 10 kg(dry air)/second. Consequently the remaining 40 kg(dry air)/s is not removing water from the material, but has still been heated. This heat is wasted.
>
> “It is not possible to achieve 100% of the equilibrium humidity because the rate of drying is proportional to the difference between the equilibrium and the actual humidities: the smaller the difference, the slower the rate of drying. However, many dryers could operate at higher exhaust air humidities without any significant reduction in the drying rate.”[20]

Several characteristics of a dryer can be modified to reduce energy consumption and drying rate. For example, the area of contact between air and material, length of the dryer, and the rate at which air moves can all be increased. These factors are best

---

[20] *Learning from Experiences with Industrial Drying Technologies*, CADDET Energy Efficiency Analysis Series No. 12, p. 56, CADDET, Sittard, Netherlands, 1994.

considered during the design of the system and are usually not viable options for retrofit because of space limitations and/or reductions in the rate of system's output.

Perhaps the simplest form of heat recovery in retrofit situations is *exhaust air recirculation*. When the space is available for ductwork and the distance between the input and the exhaust is not too great, a portion of the exhaust air can be routed back to the input of the heat source, which preheats the inlet air and reduces the energy consumption at that point.

Plate or tubular heat exchangers are used where mingling exhaust air and inlet air is not advisable.

If there's no room for additional ductwork or the distance is to great to make it feasible, a "*run-around coil*" can be used. The coil contains a heating medium, like water or a water/anti-freeze mixture, which is heated by the exhaust air. The heated medium is routed through the coil to the inlet and then to the dryer where fresh air absorbs the recycled heat.

In some applications the exhaust air is cooled below the dew point and the latent heat of vaporization is released. This energy is significant but difficult to capture because the temperature is usually too low for effective recovery. A *heat pump* may be a cost-effective alternative in these applications.

Insulation

Many dryers have hot surfaces that are exposed to air. Any loss of heat through these surfaces reduces energy efficiency. Insulating exposed surfaces and repairing damaged insulation can minimize heat loss. Properly insulating flanges and valves can help, as well.

The importance of good insulation cannot be overestimated. Poor insulation may reduce the effectiveness of other system changes like increasing the temperature differential in order to improve the productivity of the dryer. Higher temperatures and inadequate insulation means more radiant heat loss and wasted energy.

Good Housekeeping

Poor maintenance can increase energy consumption by as much as 10 percent. A few easy housekeeping measures can help to minimize wastefulness:

- Check burner efficiency in heaters.
- Check heat exchangers for fouling and leaks.
- Check filters for fouling and increases in pressure drop.
- Look for water leaks; inspect steam traps regularly.
- Check for air leaks; make sure that doors fit well and seals work.
- Have instruments serviced regularly according to the manufacturer's recommendations.
- Check thermocouples and humidity sensors for fouling.

Economic Benefit

When calculating payback on energy-efficiency projects, it is important to include indirect and non-energy-related benefits.

For example, indirect energy savings are realized if an improvement to a control system reduces the amount of product that doesn't meet specifications. In other words, total output is reduced, which, in turn, saves energy.

Non-energy-related benefits include an increase in system capacity that occurs when a bottleneck resource is able to produce more product for which there is an immediate customer demand. Continuing with the previous example of an improved control system, if better control reduces the volume of rejected product or increases the product feed rate so that daily output can be increased and if that additional capacity can be converted into additional sales, profit will increase significantly. This is because the additional sales will come with no additional operating expense, and the entire amount of the selling price (above the cost of raw materials and shipping) will go directly to the bottom line.

In many cases, the non-energy-related financial benefits are far greater than the direct and indirect energy-related savings. If correctly identified and accounted for, these additional dollars reduce the actual payback period to a matter of a few months.

RESOURCES

Printed Material

Learning from Experiences with Industrial Drying Technologies, CADDET Energy Efficiency Analysis Series No. 12, p. 56, CADDET, Sittard, Netherlands, 1994.

Singh, R.P. and Heldman, D.R., Introduction to Food Engineering, Academic Press, 3rd ed., 2001.

Wulfinghoff, D.R., Energy Efficiency Manual, Energy Institute, MD, 1999.

On-Line Tools

Earle, R.L., Unit Operations in Food Processing: http://www.nzifst.org.nz/unitoperations/index.htm

Energy Manager Training: http://www.energymanagertraining.com/new_index.php

Online Chemical Engineering Information, Pinch Technology: Basics for Beginners: www.cheresources.com/pinchtech1.shtml.

Singh, Paul, Teaching Resources: Animation: http://www.rpaulsingh.com/animated%20figures/animationlist.htm

Organizations

Association of Energy Engineers: www.aeecenter.org

International Energy Agency: www.iea.org

Iowa Energy Center: www.energy.iastate.edu

Iowa State University Industrial Assessment Center (IAC): (515) 294-3080 or www.me.iastate.edu/iac

7. Process Heating

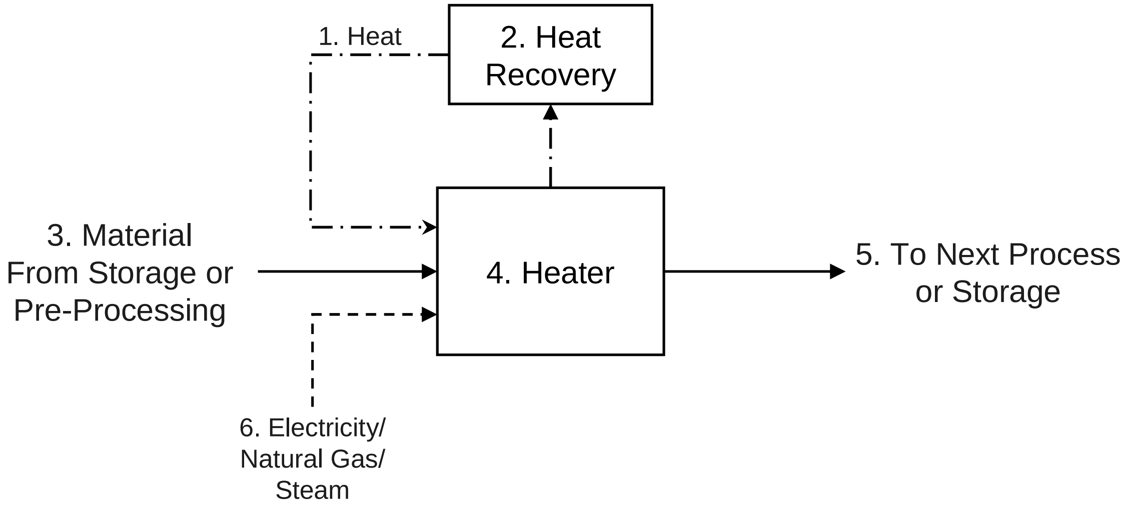


Figure 7.1 – Process heating layout

Process heating denotes all methods of heat transfer used to produce a manufactured good. The energy used to generate the heat can come directly from the combustion of a fuel, electricity, or by means of steam or hot water. In the food industry, process heat is often used for drying, cooking, or accelerating separation processes.

PROCESS HEATING SYSTEM OVERVIEW (REFER TO FIGURE 7.1 ABOVE)

Generation

Heat can be directly or indirectly generated. With direct heaters, the heat is produced within the end use equipment and material (e.g., direct electric heaters). Indirect heaters, on the other hand, use energy transformed to heat by separate equipment (e.g., generated by a boiler or heat exchanger).

Electric heaters can also be divided into the following categories:

- dielectric heaters
- resistance and induction heaters
- infrared (IR) heaters

Note that heaters are categorized according to the method used to generate the heat. Dielectric heaters use the heat generated by an electric field that alternates at radio or microwave frequencies. The radiated heat is absorbed by the material at a rate dependent on its physical properties. Resistance and induction heaters utilize an electric current to heat the material. Resistance heating can be direct or indirect. Direct resistance heating occurs as the electric current is passed directly through the material. Indirect resistance heating uses a heating element that, in turn, transfers heat either to the product or a fluid (liquid or gas) medium. IR heaters utilize electromagnetic wave radiation to directly heat the material area that is exposed to the infrared waves without heating the surrounding environment.

Heat Transfer

In general, heat can be transferred in one of three different ways or in any combination of the following: convection, conduction, or radiation. Convection occurs when two fluids (liquid or gas) at different temperatures mix together. Convection can be forced or free, depending on whether the fluids mix with the assistance of a fan or naturally by temperature differences.

Conduction heat transfer takes place when the heating source is in direct contact with the object being heated. For example, conduction occurs when a heating element is immersed in water.

Radiation, or radiant heat transfer, occurs when energy in the form of electromagnetic waves is emitted from a material and absorbed by a substance. Heat is only generated when the waves reach the target and not during the transmission process. As examples, microwave ovens and infrared heaters use radiation heat transfer.

ENERGY SAVINGS OPPORTUNITIES AND RELATED BEST PRACTICES

The following paragraphs describe various opportunities for energy savings related to process heating. The U.S. Department of Energy has developed a program that identifies energy saving opportunities. The program is called “Process Heating Assessment and Survey Tool (PHAST)” and is available at no cost on the Industrial Technologies webpage[21]. On this same site, the Department of Energy offers other programs that can be used to assist in making energy-efficiency decisions.

Heat Generation

Efficient Combustion

In order for combustion to take place, there must be a mixture of fuel and air (i.e., oxygen). Since the imperfect mixing of air and fuel molecules makes it nearly impossible to supply the precise volume of air needed for perfect combustion, it is generally recommended that a small amount of excess air be available to assure that complete combustion takes place. If too much air is used during the combustion, energy is vented in the exhaust and stack temperature rises. If not enough air is present in the mixture, incomplete combustion takes place and fuel is wasted. Take into account that air entering the combustion chamber from equipment leaks will also change combustion efficiency.

Periodic testing and adjustments to the burner are recommended to ensure efficient combustion. All air leakage and infiltration to the equipment should be stopped. Contact the burner manufacturer for safety procedures and instructions before doing adjustments, and always adhere to the applicable codes. Combustion analyzers can be used to measure

---

[21] http://www.oit.doe.gov/bestpractices/software_tools.shtml.

stack gases and determine O_2 levels and combustion efficiency. Adjustments to the air/fuel mixture should be done at different firing rates along the air/fuel ratio curve to assure good combustion efficiency. Beyond energy savings, nitrogen oxides (NO_X) formation is also greatly decreased with reductions of excess air.

Preheating Combustion Air

All air in the air/fuel mixture consumes energy as it is heated to combustion temperature. A best practice is to preheat the combustion air using energy from a source that would otherwise be wasted, such as hot exhaust gasses. It is common to collect warmer air from places such as near the ceiling, or to use an air-to-air heat exchanger for the purpose of preheating combustion air. The warmer air can be collected from a point close to the ceiling or stack.

When retrofitting an existing system for preheating the air, attention must be paid to the capacity of the fans and the air/fuel ratio curve. Warmer air contains less oxygen per unit volume, thus a larger fan or additional fans, and changes to the burner firing rate settings may be needed to assure efficient combustion. A method known as pinch technology[22] can be used to engineer an integrated heat recovery system that optimizes the balance between heat recovery and combustion efficiency.

Heat Recovery

Process heat is never fully used in its various applications, thus it is a source of energy if the heat can be recovered and used elsewhere. Commonly, heat exchangers are used for heating air for HVAC, combustion air, or liquids (water or products). In the food processing industry, the recovered heat is commonly used to heat water for wash stations. When high-temperature gases are being exhausted, the energy can be recovered and used on lower temperature applications. The U.S. Department of Energy estimates that potential energy savings from heat recovery can be as high as 25%.

Insulation

All process heating equipment loses some heat to the environment and therefore wastes energy. However, heat losses can be minimized by properly insulating the equipment. DOE’s Industrial Technologies Program offers free software for choosing proper insulation material and thickness. The software is called 3E Plus and is available for free at the Best Practices webpage[23]. According to the Industrial Technologies Program from DOE, good insulation has a potential energy savings of 2%-15% and a typical payback period of 3-12 months.

Heat transfer

With usage and time, equipment tends to become dirtied, and heat transfer becomes inefficient since the accumulation inside the equipment acts as insulation. It is a best

---

[22] Pinch technology is a set of thermodynamically based methods for finding the minimum energy usage for a network of heat exchangers.

[23] U.S. DOE ITP Best Practices, http://www.oit.doe.gov/bestpractices.

practice to frequently clean the heat transfer surfaces of indirectly heated systems, such as radiant tubes, steam coils, and electrical elements.

Direct heating systems are more efficient and easier to control than indirect systems. Because of these advantages, serious consideration should be given to replacing indirect heating systems with direct heating systems where retro fitting is possible.

Sensors and controls

DOE estimates that good process sensors, controls, and process management can result in an energy savings as high as 10%. To ensure ongoing savings, sensors and controls need to be regularly maintained and calibrated according to the manufacturer’s procedure.

System Design

In many cases, changing the system design can significantly improve energy efficiency and throughput. Common effective changes involve altering equipment in order to contain the heat, thus decreasing the amount of energy that is wasted. As an example, heat can be contained by simply installing covers in places such as tanks and ovens, slightly changing the initial design of the equipment.

Local Heating

In some cases, decentralizing heating operations may improve the overall energy efficiency of the plant. In many cases, a central boiler produces steam for all heating purposes plantwide. As energy efficiency projects that recover wasted heat are implemented, the demand for steam tends to decrease, and the burners operate at lower, less efficient firing rates. When this occurs in a plant with multiple boilers, it may make sense to reduce the demand for steam even farther by installing local water heating stations that would allow the plant to shut off one of the boilers most or all of the time. The local heating equipment can be installed near the usage point, decreasing the losses from transportation. Please refer to Appendix A for more information on steam.

RESOURCES

Printed Material

Incropera, F.P. and Dewitt, D.P., Fundamentals of Heat and Mass Transfer, John Willey & Sons, 5th ed., 2002.

Moran, M.J. and Shapiro, H.N., Fundamentals of Engineering Thermodynamics, John Willey & Sons, 4th ed., 1999.

Mull, T.E., Practical Guide to Energy Management for Facilities Engineers and Managers, ASME, NY, 2001.

Singh, R.P. and Heldman, D.R., Introduction to Food Engineering, Academic Press, 3rd ed., 2001.

Wulfinghoff, D.R., Energy Efficiency Manual, Energy Institute, MD, 1999.

On-Line Tools

U.S. Department of Energy
Energy Efficiency and Renewable Energy – Industrial Technologies Program
Best Practices: www.oit.doe.gov/bestpractices
Process Heating: www.oit.doe.gov/bestpractices/process_heat

- Tip Sheets
- Technical Publications
- Supplement to the *Energy Matters* newsletter

Software Tools: www.oit.doe.gov/bestpractices/software_tools.shtml

- Process Heating Assessment and Survey Tool (PHAST)
- Steam System Scoping Tool
- Steam System Assessment Tool (SSAT)
- 3E Plus – Insulation Thickness Computer Program

Energy Information Bridge: www.osti.gov/bridge

Energy Matters: www.oit.doe.gov/bestpractices/energymatters/energy_matters.shtml

Online Chemical Engineering Information, Pinch Technology: Basics for Beginners: www.cheresources.com/pinchtech1.shtml.

The Carbon Trust: www.thecarbontrust.co.uk
Publications: www.thecarbontrust.co.uk/energy/pages/publication_search.asp

Organizations

Association of Energy Engineers: www.aeecenter.org

The Carbon Trust: www.thecarbontrust.co.uk/energy/pages/publication_search.asp

Gas Research Institute: www.gri.org

International Energy Agency: www.iea.org

Iowa Energy Center: www.energy.iastate.edu

Iowa State University Industrial Assessment Center (IAC): (515) 294-3080 or www.me.iastate.edu/iac

8. Refrigeration

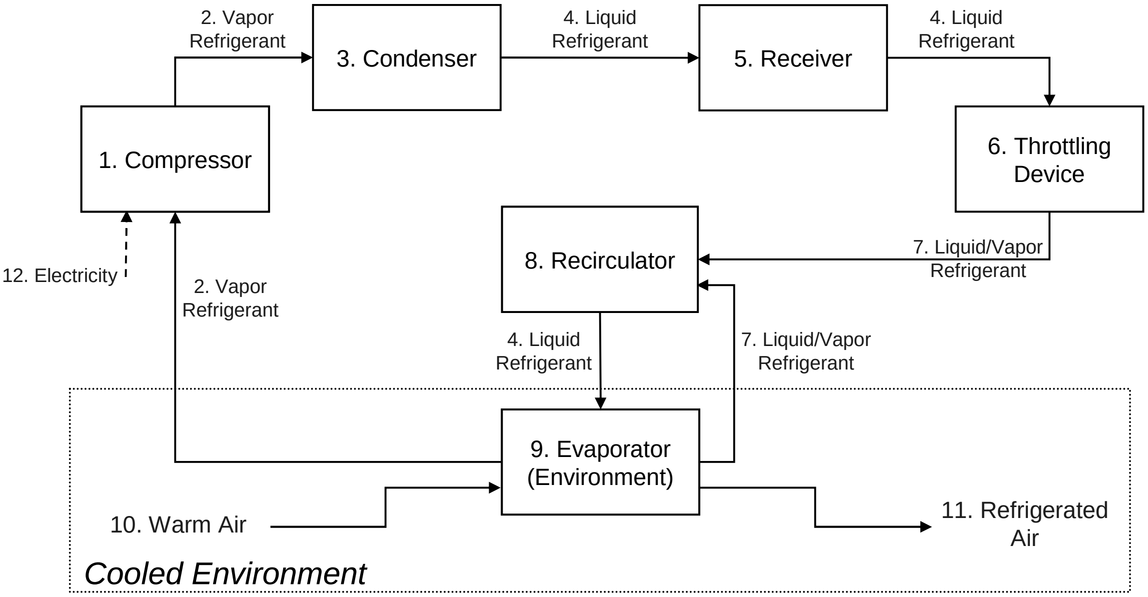


Figure 8.1 – Refrigeration system layout (single stage)

The food industry has benefited greatly from the development of mechanical refrigeration systems. Perishable products can be kept safe for longer periods of time when processing and storage environments can be maintained at constant temperatures. Refrigeration systems and their applications continue to evolve into more reliable, safer, and less expensive operations. A general description of a refrigeration system follows.

REFRIGERATION SYSTEM OVERVIEW (REFER TO FIGURE 8.1 ABOVE)

The basic refrigeration cycle used by most food processors consists of four major components: compressor (1), condenser (3), throttling device (6), and evaporator (11). Most systems also use a receiver (5) to provide a buffer for refrigerant as demand varies and a recirculator (8) to pump the refrigerant to multiple evaporator units.

Refrigerants

Different fluids can be used in a refrigeration system as the medium for heat transfer. To create good system performance, the ideal refrigerant should have a high evaporative pressure and a low condensing pressure. For more than 100 years, ammonia has been the refrigerant most widely used by the food processing industry; approximately 90% of food processors rely on it.

Compressor (1)

The compressor keeps the refrigerant flowing so it can absorb energy from a cold region and transfer it to a hot region. Compressors change the refrigerant from a low-pressure vapor to a high-pressure vapor and move it through the system. Very low temperatures are required (e.g., -40°F) to freeze a product. Therefore, in order to operate efficiently, freezing operations generally use a two-stage system with a low-pressure or booster compressor and a high-pressure compressor.

Compressors can be classified as open or hermetically sealed. Open compressors, which are mostly used for large applications, have an external drive like an electric motor or gas engine. The drive motor and compressor of hermetically sealed equipment are enclosed within a frame. Refrigeration compressors, like air compressors, are often categorized as:

- Dynamic
  - Centrifugal
- Positive displacement
  - Reciprocating
  - Rotary Screw
  - Scroll

Centrifugal compressors are very efficient if they are working at full capacity. They pressurize the refrigerant vapor by centrifugal force from a single or series of impellers. This type of compressor is used in large water chilling applications.

Reciprocating and rotary-screw compressors are common in food manufacturing operations that use ammonia refrigeration. Reciprocating compressors generate pressure from pistons that compress the refrigerant within a cylinder. Rotary-screw compressors may have single or twin screws. The rotary-screw compressors trap the refrigeration within the helical treads of the rotor, moving it forward and decreasing the space between the treads as it rotates. Oil injected into a compressor not only provides lubrication, but also seals the compressor and helps cool it.

In scroll compressors, the refrigerant is compressed by a scroll-shaped vane that rotates within a fixed vane, decreasing the space available for gas as it rotates.

Capacity control for the refrigeration system plays an important role in saving energy. Not all types of compressors can be controlled the same way. Some capacity control methods are listed below:

- on-off
- suction valve unloading
- speed control
- hot gas bypass
- slide valves
- variable pitch inlet guide vanes
- suction dampers

The on-off control is the simplest. A thermostat indicates when the environment has reached a predetermined temperature, and the compressor shuts off. The compressor is turned back on if the temperature rises above a set limit. This type of control is most suitable for small capacity systems.

The suction valve unloading method works by lifting the suction valves of some cylinders to the open position. The gas cannot be compressed within the open cylinders, which results in an efficient reduction of refrigeration capacity.

Installing a variable speed drive or a multi-speed motor on the compressor allows the equipment to reduce capacity by reducing motor speed. Compressor rotational speed can then be varied to match the system’s changing requirement for refrigeration capacity.

The capacity of reciprocating and centrifugal compressors can also be controlled by bypassing hot gas from the discharge port to the suction port of the compressor, creating an artificial load on the system. This is very inefficient.

Reciprocating compressors can take advantage of the first five control methods. The capacity of screw compressors is commonly controlled by a slide valve or speed control.

Rotary-screw compressors use slide valves to adjust the necessary refrigeration capacity at partial loads by permitting the equipment to reduce the total volume of refrigerant compressed within the housing.

There are three ways to control the capacity of centrifugal compressors:
- speed control
- variable pitch inlet guide vanes
- suction dampers

The first method, speed control, is achieved by using variable speed drives or multi-speed motors, as discussed earlier. The second method, variable pitch inlet guide vanes, uses adjustable vanes that prepare the refrigerant vapor as it enters the rotating impeller by sending the vapor in the same direction as blade rotation. The compressor remains at a constant rotational speed, but the refrigeration capacity is altered. The third method, suction dampers, alters inlet pressure to the compressor, therefore altering the volumetric flow of refrigerant into the compressor. Suction damper capacity control is inefficient.

Condenser (3)

The condenser transfers the heat from the refrigerant to a coolant medium, usually ambient air. Inside the condenser the refrigerant changes from a vapor to a liquid. There are three basic types of condensers:
- air-cooled
- water-cooled
- evaporative

With air-cooled condensers, fans force air through a bank of coils containing the refrigerant vapor. The air absorbs the heat as it passes by the coils and cools the refrigerant. The condensing capacity of a system can be increased by forcing more air through the coils or by providing more heat transfer surface area. Cooling capacity is directly related to the difference of the condensing temperature of the refrigerant and the air temperature (dry bulb).

Water-cooled condensers use water as the medium that absorbs heat. A shell-and-tube heat exchanger, for example, has water flowing through the tubes and refrigerant in the shell. The water source is normally a cooling tower, and the water is circulated to continuously absorb heat from the refrigerant. This type of condenser is used most commonly with large chillers and sometimes in large refrigeration systems.

An evaporative condenser is a combination of an air-cooled and a water-cooled condenser. As the hot refrigerant vapor flows though the bank of tubes, water is sprayed over the tubes and evaporates. As the water evaporates, it absorbs heat from the refrigerant, which increases the efficiency of the condensation. Because of the increased efficiency, evaporative condensers can be smaller than air-cooled units.

Evaporative condensers are wet-bulb temperature sensitive and they condense refrigerant to within 10 to 15°F of the wet-bulb temperature. As a result, these condensers are the most efficient of all types.

Receiver (5)

The receiver serves as a buffer for liquid refrigerant to be stored for use by the system. The liquid refrigerant is taken from the receiver to the evaporators as needed to satisfy the load. A receiver is needed when the system refrigeration load varies greatly.

Throttling Device (6)

The throttling device separates the high-pressure and low-pressure sides of the system. It reduces the refrigerant pressure and controls the flow rate of refrigerant to the recirculator—or directly to the evaporator in systems that do not have a recirculator. The following are types of throttling devices:

- thermostatic expansion valve
- constant pressure expansion valve
- float valves
- modulating valves

The thermostatic expansion valve automatically adjusts the flow rate of refrigerant needed to satisfy the refrigeration load based on the temperature of the refrigerant vapor leaving the evaporator.

The constant pressure expansion valves are basically pressure regulating valves that control the pressure at the evaporator. Because these valves only adjust to the pressure, they are limited to constant cooling loads.

Float valves are divided in two categories: high-side and low-side. The high-side float valve controls flooded liquid chillers systems with a single compressor, condenser, and evaporator. The high-side valve is installed on the high-pressure side of the throttling device and adjusts the flow of liquid refrigerant to the evaporator. Low-side float valves can be used in systems with multiple evaporators and are placed on the low-pressure side of the throttling device.

Modulating valves are normally operated electrically (electronically), but pneumatic modulating valves are also available. The modulating valve gradually feeds the liquid from the receiver to the recirculator in response to a liquid level sensor in the recirculator vessel. This type of feed valve keeps the flow of refrigerant in direct response to the refrigeration load requirements, which more effectively limits the amount of flash gas that makes it to the compressors. This system replaces the old solenoid valve, hand expansion valve, and level sensor, all of which tended to feed erratically and kept the compressors' capacity reduction systems working overtime.

Recirculator (8)

Liquid recirculation systems are designed to recirculate three to four times the amount of evaporated refrigerant. This guarantees total wetting of the evaporator tube surface and also ensures the return of any lubricant that may be in the circulated refrigerant. Compared to flooded evaporators, recirculation minimizes the amount of refrigerant in the system. The return piping from the evaporators will contain both vapor and liquid refrigerant.

The re-circulation of the refrigerant is done in two ways:
- gas pressure pumping
- mechanical pumping

The gas pressure pumping system (not shown in Figure 8.1) utilizes the high pressure of the hot vapor to push the cold liquid, which is at a lower pressure, to the evaporators. This is an inefficient system but is sometimes used when electrical power, which is required for mechanical pumping, is not available or could not be safely used.

Mechanical pumping normally uses electric motor-driven pumps to distribute the liquid refrigerant to the evaporators. Pumps used for this function can be semi-hermetic (canned) or open type.

Evaporator (11)

Inside the evaporator heat from the cooled region or medium is absorbed into the refrigerant, and, as a result, the refrigerant changes from a liquid to a vapor. The evaporator can be of the following types:
- liquid coolers
- air and gas (unit) coolers

Liquid coolers use shell-and-tube heat exchangers to chill process liquids (e.g., water and milk) or fluids used on air conditioning coils. Shell-and-tube heat exchangers are limited to 38°F water to prevent freezing.

Another type of liquid cooler is the 33°F baudelot water chiller, which circulates water over refrigerated plates. This permits water to be chilled to 33°F without the possibility of freezing, which may occur in a shell-and-tube heat exchanger.

Air and gas coolers, also known as unit coolers, can be either flooded or dry. Dry types of air and gas coolers are preferred due to their minimal need for refrigerant. Frost will occur on the coils of unit coolers when the temperature of the coil falls below 32°F. Frost acts as an insulator, which reduces the efficiency of the system. Common defrosting techniques are

- isolation of the coils
- water defrost
- hot gas defrost

Isolating coils was one of the first techniques used to defrost coils in rooms above 38°F. Careful design of the room allows the coils to be separated from the cold region so warm air can be circulated over them without increasing the total refrigeration load. Another method of defrosting isolated coils is the use of electric heat.

Water defrosting is done by applying water over the coils to remove the frost. However, careful consideration to the flow and temperature of the water must be taken to make sure that it does not freeze on the coil or on the return from the cold room. This is the most efficient defrosting method.

Hot gas defrost is the most commonly used method of defrosting in large-scale applications. During the defrost cycle, hot refrigerant gas from the discharge of the compressors is sent through the coils to melt the frost. This method can be efficient and inexpensive to install, but control valves must be used for safe and reliable defrosting.

Air Infiltration

Air sometimes can enter the system and mix with the refrigerant, greatly reducing overall efficiency. Air can enter the system

- when it’s open for repair
- when it’s being filled with refrigerant or oil
- through seals and valves if the suction pressure is below the atmospheric pressure

Air can be purged in two basic ways: manually or automatically. Manual removal of air is accomplished using a strategically positioned valve that is opened by hand as required. Automatic purgers can be mechanical or electronic.

ENERGY SAVINGS OPPORTUNITIES AND RELATED BEST PRACTICES

Refrigeration plays an important role in food safety. For many food processors working with perishable items, refrigeration can be the most costly component of the operation, accounting for over 50% of the electric bill. Therefore, significant financial benefit can be realized by using the following best practices to improve refrigeration.

Compressor

Compressor Maintenance

Predictive maintenance of the compressor and refrigeration system will result in the following benefits:

- fewer shut-downs to conduct emergency repairs
- reduced maintenance costs (planned maintenance is always cheaper than emergency repairs)
- less overtime pay (hours can be planned, not scheduled around emergency repairs)
- extended lifespan for equipment (properly maintained equipment lasts longer)
- a safer work environment (can result in a decrease of insurance cost)

As part of the predictive maintenance program, the following should be performed:

- vibration analysis of rotating equipment
- pipes and vessels thickness testing
- infrared inspection of all equipment, piping, electrical gear, and insulation
- lubricant usage monitoring

A good vibration analysis will identify potential problems on rotating equipment. Anticipating and repairing potential problems before they develop can minimize larger problems. Certain types of insulation retain humidity and can promote the formation of rust on the encapsulated pipe or vessel. It is recommended that an insulation inspection and vessel thickness testing be performed regularly on pipes and vessels, such as the recirculator.

An ultrasonic gauge is a relatively inexpensive and accurate tool for this type of thickness (gauge) measurement. Insulation technology has evolved over time, bringing new products for rust resistance and better efficiency. Apply a rust inhibitor on pipes and vessels before re-insulating them.

Compressor lubricant should be tested regularly for impurities. A coalescent separator can be installed on the system to decrease oil carryover into the refrigerant. Large amounts of oil in the refrigerant (ammonia) can cause foaming, which can damage compressors. An oil analysis should be performed about every six months to identify possible problems with the system.

Lubricant leakage and carryover into the refrigerant can be identified by closely tracking the amount of oil put into and removed from the system. These two quantities should be essentially the same.

Thermosyphon Lubricant Cooling

The lubricant in a compressor is also responsible for cooling the compressor and keeping it sealed. Lubricants absorb heat, so to keep a compressor running effectively, the lubricant must be cooled. This can be done in different ways.

One method of cooling the lubricant is direct injection of refrigerant in the compressor housing. This method is inefficient and can also damage the compressor. Direct injection cooling can decrease overall efficiency of a screw compressor by as much as 10% for systems with a high compression ratio and 5% for systems with a low compression ratio. A pump can be added to the system to inject a high-pressure refrigerant, thereby reducing efficiency losses. However, this may lead to over-injection of refrigerant and may severely damage the compressor.

A good solution for lubricating screw compressors is to add an indirect cooling system. This system can use a heat exchanger (plate-and-frame or shell-and-tube) with cooling tower water, a section of an evaporative condenser, or a thermosyphon system (using refrigerant) to exchange heat between the hot lubricant and refrigerant. Since the oil needs to be decreased by only a few degrees, a high-pressure refrigerant can be used to accept heat from the lubricant. The thermosyphon cooling system eliminates the need for a pump and can save a large percentage of motor horsepower. Condenser water can also be used for the thermosyphon, although it tends to collect more impurities, so the system will need to be periodically cleaned.

Thermosyphon Cooled Desuperheater

A thermosyphon cooled desuperheater can be added to keep the refrigerant at a lower temperature. Making this addition to the system's low-stage compressors can remove approximately 60°F (41.5 Btu/lb of ammonia) from the discharge refrigerant, which, in turn, removes the same amount of work from the high-stage compressors, saving a significant amount of energy.

Raise System Suction Pressure

As ambient temperature decreases, the load on the refrigeration system usually decreases as well. When this occurs in two-stage systems, a simple way to save energy is to slowly increase the suction pressure/temperature of the low-stage compressors. It is estimated that energy savings of about 8% can be realized with two-stage systems when the suction temperature (and therefore pressure) is raised from -30°F to -20°F. For a system with blast freezers, savings can be even greater (12%) if the temperature/pressure is increased from -40°F to -30°F. A slow step increase in pressure/temperature is recommended in this case. It is estimated that high-stage compressors can save approximately 8% of motor break horsepower for a rise of 10°F in suction temperature.

Older two-stage systems have rotary booster compressors with limited compression ratios, and, therefore, the intermediate pressure cannot exceed approximately 20 psig. Many of these old compressors have been replaced with rotary-screw compressors that can tolerate higher compression ratios, but the intermediate pressure has been left at 20 psig. In such cases, the intermediate pressure should be adjusted upward. This will decrease the energy usage per ton of refrigeration. The optimum intermediate pressure equalizes the absolute compression ratio between the two stages.

High Efficiency Motors

Installing premium efficiency motors and variable frequency drives (VFD) on compressors and condensers may significantly reduce energy consumption. The use of a VFD is most beneficial for air-cooled and evaporative condensing systems with large differences between required and installed condenser capacities. Refer to the motors appendix of this document for more details.

Condenser

Operate Condenser at Lowest Possible Pressure

To save energy when compressing refrigerant, the condensing temperature/pressure should be set as low as possible. Many operators complain that their system cannot operate at low pressures. However, the true cause of most of the complaints can be linked to a problem that's unrelated to lower condensing pressure. For example, a common complaint is that hot gas defrost cannot be operated at pressures below 150 psig. However, in most cases, the insufficient amount of hot gas for effective defrosting is explained by undersized piping rather than lower pressure.

Microprocessor controllers can be installed on the condensing system to ensure that minimal condensing pressure is used and to efficiently sequence the use of fans and water on the condenser. The processor should take into consideration temperatures and pressures of the system as well as ambient wet-bulb temperature. The pressure/temperature of the system should be at about 10°F above wet-bulb temperature, the temperature at which water will evaporate on a given day (which is greatly affected by the amount of humidity in the air).

Significant energy savings can result from installing a microprocessor controller on the condensing system. Installing such a system typically has a very short pay-back period.

Use Axial Fans on Condenser

Because air-cooled or evaporative condensers do not need high-pressure air, axial fans are well suited to this application. Axial fans use approximately 50% less energy than centrifugal fans and adequately do the job required by the condenser.

Heat Recovery from Refrigeration System

Heat should be recovered from as many industrial processes as possible. Of course, it is important to compare the capital investment for such systems to potential energy savings before making a decision or an investment. Heat recovered from the refrigeration system is commonly used to preheat boiler feedwater or to heat water that is used for equipment cleanup. This is done using a shell-and-tube heat exchanger in parallel with the condenser. During warm months, water temperature may be increased up to 45°F by the heat reclaimed from the condenser. This saves money by significantly reducing the amount of energy needed to heat the water. During cold weather, the refrigeration system has to do less work, and, therefore, it is possible to reduce the pressure at which the compressors operate. A positive result is a significant reduction in the energy needed to power the compressor; on the negative side, there is also a significant reduction in the amount of heat that can be recovered at the condenser. In most cases the energy savings from operating compressors at a lower pressure during cold months is greater than the savings from heat recovered at the condenser.

Throttling Device

Sizing and Operation of Throttling Devices

When the thermostatic expansion valve is working properly, the temperature difference from the inlet and the outlet of the valve is very noticeable. A smaller than normal temperature difference between the inlet and the outlet of the throttling device means that the pressure drop inside the valve is less than it should be. This can be caused by a clogged (dirty) or damaged valve seat.

If the throttling device is undersized, the condenser must be kept at high pressures to force enough refrigerant through the system. Therefore, if the supply of refrigerant is insufficient for the cooling load, the throttling device should be inspected as a possible reason. The day-after-day savings of running at a lower system pressure will quickly repay the one-time expense of a larger throttling device (and, possibly, larger piping).

Evaporator

Demand Defrost

The concept behind demand defrost is to defrost the system when, and only when, necessary. This differs from timed systems that defrost at a set interval, regardless of need. Demand defrost should be used for refrigeration areas below freezing point. The defrost cycle starts based on pressure readings from sensors located across the coils. An increase in pressure drop indicates the presence of frost over the coils and activates the defrosting system. The liquid refrigerant formed during defrost should be drained and piped to the high-temperature recirculator or intercooler.

Correct Size of Pipe for Defrost

In most cases, when reducing condensing pressure doesn’t initiate defrost, the problem is incorrect sizing of the defrost piping. Piping should be redesigned to allow for sufficient hot gas flow.

Dedicate Compressor for Defrost

If reducing the pressure on the condenser will cause insufficient hot gas for defrosting and correcting the pipe size is not feasible, significant energy savings may still be realized. One compressor of a large system can be dedicated to running at the pressure needed for the defrost cycle, while the other equipment can be dedicated to lower-system pressure. Savings from reducing the condensing pressure are generally greater than the cost of dedicating a compressor.

Air Purging

Air must be purged from the system. An automatic purger should be installed to decrease refrigerant loss during the process and reduce the possibility of operator error.

Recirculator

Use Mechanical Pump for Recirculation System

Studies have proven that mechanical pumping of liquid refrigerant on recirculation systems is more efficient than hot gas pumping. An electric liquid refrigerant pump can be installed on the recirculation system to push the needed refrigerant to the evaporators. A hot gas pumping system operating at 15 psig with a condensing pressure of 185 psig and capacity of 500 tons of refrigeration can waste approximately 30 hp. A 5 hp electric pump can be substituted, resulting in significant energy savings.

RESOURCES

Printed Material

ASHRAE Standard 15-1992, Safety Code for Mechanical Refrigeration.

ASHRAE Standard 34-1992, Number Designation and Safety Classification of Refrigerants.

Briley, G.C., Hot Gas Defrost Systems for Large Evaporators in Ammonia Liquid Overfeed Systems, IIAR 14th Annual Meeting, Miami, FL, March 1992.

Briley, G.C., Increasing Operating Efficiency, p. 73, ASHRAE Journal, May 2003.

Briley, G.C., Energy Conservation in Industrial Refrigeration Systems, pp. 46-47, ASHRAE Journal, June 2003.

Briley, G.C., Efficiency for R-717 and R-22 Systems, p. 87, ASHRAE Journal, July 2003.

Briley, G.C., Efficiency for R-717 and R-22 Systems – Part 2, p. 53, ASHRAE Journal, August 2003.

Briley, G.C., Efficiency for R-717 and R-22 Systems – Part 3, p. 58, ASHRAE Journal, September 2003.

Briley, G.C., Efficiency for R-717 and R-22 Systems – Part 4, p. 60, ASHRAE Journal, October 2003.

Briley, G.C., Efficiency for R-717 and R-22 Systems – Part 5, p. 58, ASHRAE Journal, November 2003.

Corinchock, J.A., Technician's Guide to Refrigeration Systems, McGraw-Hill 1997.

Dinçer, I., Refrigeration Systems and Applications, John Willey & Sons, 2003.

Moran, M.J. and Shapiro, H.N., Fundamentals of Engineering Thermodynamics, John Willey & Sons, 4th ed., 1999.

Mull, T.E., Practical Guide to Energy Management for Facilities Engineers and Managers, ASME, NY, 2001.

Singh, R.P. and Heldman, D.R., Introduction to Food Engineering, Academic Press, 3rd ed., 2001.

Stoecker, W.F., Industrial Refrigeration Handbook, 1998.

Wulfinghoff, D.R., Energy Efficiency Manual, Energy Institute, MD, 1999.

On-Line Tools

U.S. Department of Energy
Best Practices: www.oit.doe.gov/bestpractices
Fact Sheets: www.oit.doe.gov/factsheets/fact_other.shtml#bp

Energy Information Bridge: www.osti.gov/bridge

Energy Matters: www.oit.doe.gov/bestpractices/energymatters/energy_matters.shtml

Gartner Refrigeration and Manufacturing: www.gartner-refrig.com
Tips and Tools: www.gartner-refrig.com/resources/tips.asp

The Industrial Refrigeration Consortium: www.irc.wisc.edu.
Downloads: www.irc.wisc.edu/software/downloads.php
Publications: http://www.irc.wisc.edu/publications/

Organizations

American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE): www.ashrae.org

The Industrial Refrigeration Consortium: www.irc.wisc.edu

International Institute of Ammonia Refrigeration: www.iiar.org

Iowa State University Industrial Assessment Center (IAC): (515) 294-3080 or www.me.iastate.edu/iac

9. Industrial Air Handling

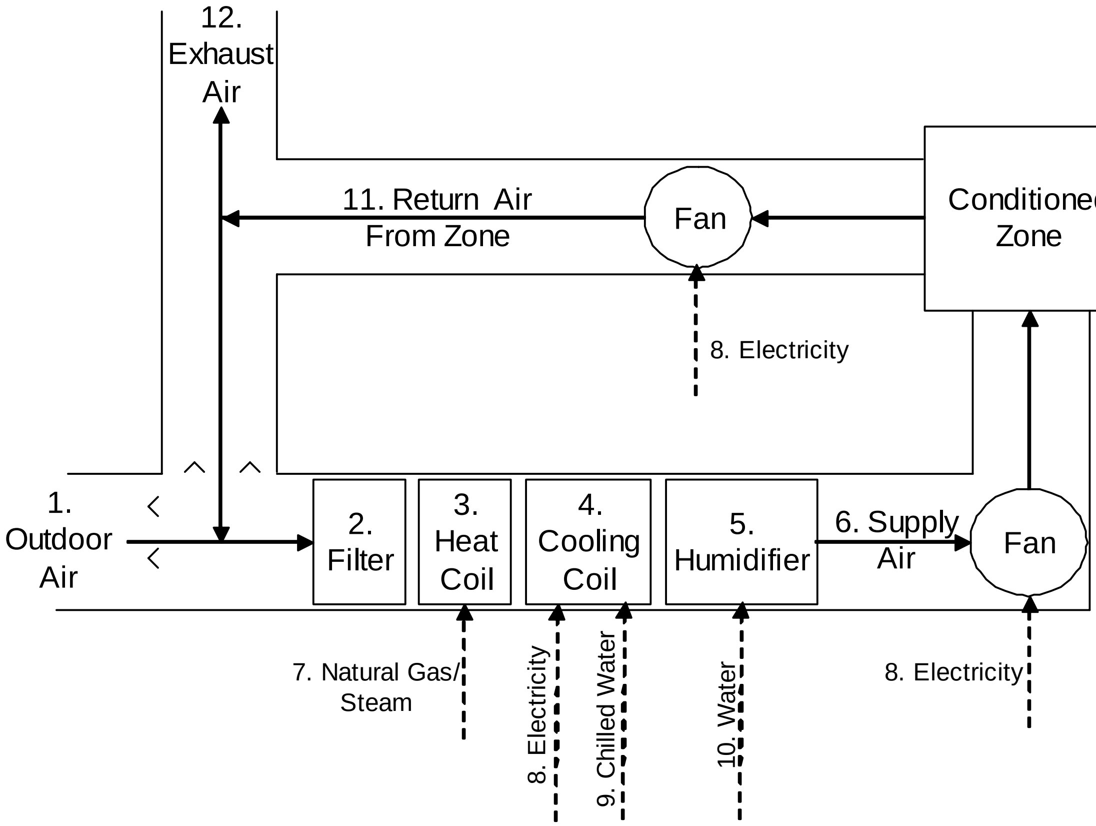


Figure 9.1 – Industrial air handling system

Many parts of industrial facilities are designed to maintain the environment within acceptable limits of temperature, humidity, and pollutants. In the food industry, for example, air pollutants are kept at the lowest possible level in order to keep the product from becoming contaminated. By legislation, office areas must also be kept within maximum allowable levels of contaminants to ensure the well being of occupants.

AIR HANDLING SYSTEM OVERVIEW (REFER TO FIGURE 9.1 ABOVE)

The primary functions of an industrial air handling system are to heat, cool, and clean the air, humidify or dehumidify it, and provide ventilation. Commercial and industrial systems can be configured in several different ways; Figure 9.1 illustrates a general case.

Here's how an industrial air handling system works: Outside air (1) and return air (11) from the conditioned zone[24] mix in order to maintain allowable levels of impurities and to keep energy usage to a minimum. Outside air is introduced into the system to keep the zone well ventilated and maintain good indoor air quality (IAQ). The mixed air subsequently passes through a filter (2) before it is heated or cooled. A heating fluid,

---

[24] According to McQuiston et al., a zone is a conditioned space under the control of a single thermostat.

commonly hot water or steam, must be supplied to the heating coil (3). The water can be heated using a water heater or steam can be used with a heat exchanger[25]. A cold fluid, usually a liquid or a mixture of liquid and vapor, must also be supplied to the cooling coil (4). Pumps are used to circulate the heating and cooling fluids through the system. A humidifier (5) can be used to keep the supply air (6) from being too dry. Spraying atomized particles of water or steam to the supply air before it is delivered to the conditioned zone usually does this.

Ventilation brings outside air into a specific zone, thus protecting the area from unacceptable levels of contaminants and odors. Carbon monoxide (CO) and carbon dioxide (CO_2) levels also must be kept low in order to maintain the comfort and safety of the area's occupants. Measuring CO_2 levels within a zone can point to incorrect ventilation rates. The Environmental Protection Agency (EPA) recommends that CO_2 be limited to 1,000 ppm[26] in areas where occupants have continuous exposure. The presence of high amounts of CO_2 in a space can cause discomfort (headaches, shortness of breath, and nausea). CO is a toxic gas, and levels lower than 15 ppm are recommended. Other gases such as sulfur oxides and nitrous oxides also can be found in conditioned zones. To ensure the health and safety of occupants, maximum allowable levels of these gases must also be observed.

ENERGY SAVINGS OPPORTUNITIES AND RELATED BEST PRACTICES

There have been changes to the codes and standards governing IAQ. The increased ventilation rates demanded by these new codes have, in turn, triggered an increase in energy consumption. Maintenance is a primary concern for companies dealing with ventilation-related projects. However, best practice projects in this area should be considered as they can generate significant energy savings. Some of these important projects are described below.

Correct Level of Ventilation

As mentioned, ventilation is an important function of an industrial air handling system. With proper ventilation, comfort can be assured, and, more importantly, health risks can be greatly minimized. Carbon dioxide is a byproduct of our metabolism, which makes it difficult (if not possible) to control its production. Carbon monoxide, however, is a byproduct of incomplete fuel combustion and smoke from tobacco products. It is possible to greatly control its production in the workplace. For example, repairing improperly vented furnace chimneys or leaky water heaters will reduce contaminants and improve air quality.

The best way of making sure that CO_2 and CO levels are not above recommended allowances is to check ventilation systems within the plant. To check whether contaminated air is being captured and circulated, make sure that outside air intakes are not located close to loading docks or areas where cars can be parked. Check indoor equipment to verify that it's functioning properly.

---

[25] Information on steam and water heaters is provided in the steam and the process heating sections respectively.

[26] Parts Per Million—ppm.

Excessive Ventilation

Excessive ventilation will not improve the comfort level of occupants in a zone, but it will increase energy usage since any extra outside air must be conditioned and delivered to the zone. Therefore, the ventilation rates of the air handling system should be well calibrated to keep indoor air quality as close to acceptable limits as possible. Refer to ASHRAE[27] Standard 62 for detailed information on recommended ventilation and contaminants rates.

Outside air dampers should be adjusted regularly to ensure the functionality of the system. Outside air intakes should also be adjusted to accommodate changes to the number of occupants in a particular zone. With modern technology, it is also possible to control the amount of outside air used based on the time of day or number of occupants in a given zone.

Economizers

An air-side economizer cycle (or economizer) is a process of using cold outside air to reduce the cooling load within a conditioned zone. This cycle consists of a strategic sequence of damper controls that supply cold air (typically around 55-65°F) directly to the zone when the system is in cooling mode. In some cases, it is less efficient to dehumidify cold air than it would be to run the system without the economizer cycle. Therefore, the economizer cycle should be controlled with enthalpy sensors that are a combination of temperature- and humidity-sensing elements. Air-side economizers can, in many instances, be easily installed into existing systems and should be considered in most facilities.

Motors

Premium efficiency motors and variable frequency drives can be used on motors powering fans and pumps. Best practices related to these topics are further explained in the motors section of this document.

Programmable Thermostats

It’s easy to install a programmable thermostat in an office area, and doing so can save energy. A programmable thermostat is basically a combination clock and thermostat that manipulates the temperature of a zone depending on the time of day.

Thermostats should also be set at the highest and lowest comfortable temperatures during the cooling and the heating season, respectively. It is estimated[28] that 90% of occupants, if they are appropriately attired for the season, will be comfortable if the temperature

---

[27] American Society of Heating, Refrigerating and Air-Conditioning Engineers – ASHRAE: www.ashrae.org.

[28] McQuiston, F.C., Parker, J.D., and Spitler, J.D., Heating, Ventilating, and Air Conditioning: Analysis and Design, Willey & Sons, 5th ed.,2000.

ranges[29] from 68° to 75°F during the winter and from about 79°F to 84°F during the summer.

Air Distribution

Air distribution can play a key role in the efficient operation of any ventilation system, since well-placed terminals and return devices can reduce the amount of air that needs to be distributed. Normally the quantity of outside air and/or supply air used can be decreased if the supply air is distributed near the work area.

Improved air distribution and air exhaust also can greatly enhance areas where humidity is a problem. Humidity levels in a food processing plant are generally high because of the large amount of water required by the process. Many plants circulate and condition the air from the entire zone, even though the source of the high humidity is confined to a small area of the zone. In such cases, the load on the air handling system can be significantly reduced by collecting the moist air at the source and exhausting it. The same principal could be used to help alleviate odors and smoke.

Destratification Fans

If an area has poor air circulation, the temperature near the ceiling can be much different than the temperature at floor level. This phenomenon is known as stratification of air temperature. Stratification in heated zones causes inefficiency because the thermostat (which is often at floor level) senses lower temperatures than if the room were not stratified. Thus the thermostat signals the need for heat, increasing the average temperature, whereas all that is needed is to move the warm air near the ceiling towards the floor. In addition, conduction losses through insulation are significantly reduced since the high temperatures around the ceiling are reduced.

Low-speed ceiling fans, or destratification fans, can be installed in heated zones to increase the movement of hot air from the ceiling towards the floor, reducing the amount of heat required to provide the desired comfort level.

Radiant Heating

Radiant systems emit directional heat that is transferred directly to surfaces and bodies but not to the air as in a forced air system. Radiant heating systems provide savings because they maintain comfort level without heating the entire space, they decrease stratification, and combustion efficiency tends to be better than conventional heating systems.

Building Insulation

Insulation is an effective way of mitigating heat loss. Well-insulated walls and ceilings will reduce heat gain during the summer and reduce heat loss during the winter. Selecting the correct insulation is important, as different areas may need different types of insulation material. Walls and ceilings should be insulated and protected from moisture

---

[29] Ranges used for low air speed: ≤30 fpm and 50% relative humidity.

and air leakage. Vapor barriers should be installed on the insulation to protect it from moisture. As with insulation in industrial equipment, the harsh environment can weaken the integrity of the insulating material. Therefore, existing insulation should be checked and fixed if necessary. Keep in mind that different construction types require different insulation materials, and the amount of insulation needed can impact its cost effectiveness.

Air Leaks

It is virtually impossible to have a perfectly sealed building. However, air leaks, which occur in corners, doors (walk-through, garage, docks, etc.), and windows, should be kept at a minimum. This problem is also found between conditioned and unconditioned areas of a facility. Most of the time, solving an air leak problem is simple. Make sure that cracks around doors, windows, and corners are well caulked, and use curtains or doors between conditioned and unconditioned areas.

Heat Recovery from Exhaust Air

All heat exhausted from the plant should be considered for recovery. In most industrial facilities, equipment like air and refrigeration compressors generate heat that can be recuperated and ducted to heated zones, effectively reducing the load on the air handling equipment. In cases where the air is not sufficiently clean for direct use in the space, heat exchangers can be used to transfer the energy to cleaner air.

RESOURCES

Printed Material

Aro, T. and Koivula, K., Learning from Experiences With Industrial Ventilation, CADDET, Sittard, Netherlands, 1993.

ASHRAE Standard 62, Ventilation for Acceptable Indoor Air Quality.

McQuiston, F.C., Parker, J.D., and Spitler, J.D., Heating, Ventilating, and Air Conditioning: Analysis and Design, Willey & Sons, 5th ed., 2000.

Wulfinghoff, D.R., Energy Efficiency Manual, Energy Institute, MD, 1999.

On-Line Tools

U.S. Department of Energy
Energy Efficiency and Renewable Energy
    Energy Savers: www.eere.energy.gov/consumerinfo/energy_savers
    Energy Matters: www.oit.doe.gov/bestpractices/energymatters/energy_matters.shtml
    Building Technologies Program: www.eere.energy.gov/buildings
        Information Resources : www.eere.energy.gov/buildings/info/publications.html
Energy Information Bridge: www.osti.gov/bridge

Oak Ridge National Laboratory (ORNL)—Buildings Technology Center
    Building Envelopes Program: http://www.ornl.gov/sci/roofs+walls/
        Insulation Fact Sheet: www.ornl.gov/sci/roofs+walls/insulation/ins_01.html
        ZIP-Code Insulation Program : www.ornl.gov/~roofs/Zip/ZipHome.html

Simply Insulate: www.simplyinsulate.com
        www.simplyinsulate.com/howmuch.html

Organizations

American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE): www.ashrae.org

The Carbon Trust: www.thecarbontrust.co.uk/energy

Iowa State University Industrial Assessment Center (IAC): (515) 294-3080 or www.me.iastate.edu/iac

North American Insulation Manufacturers Association (NAIMA): www.naima.org

Appendix A. Steam

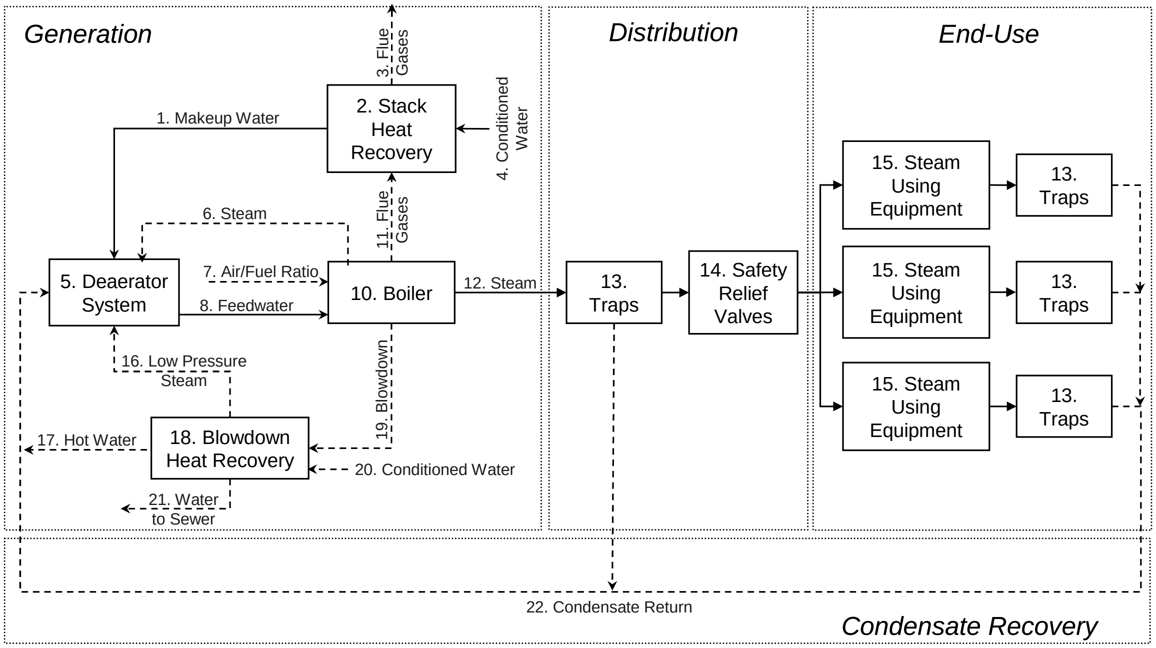


Figure A.1 – Steam system layout

Steam has a long, proud history, powering, among other things, the beginning of the Industrial Revolution. Steam's high capacity to store energy in the form of heat and move a controlled amount of it easily and efficiently throughout a manufacturing facility has, to this day, made it a popular choice for a wide variety of industrial uses. In fact, over 45% of all fuel burned by U.S. manufacturers is used to generate steam. In the food processing industry, steam is used for processes like cooking, drying, and sterilizing. A general description of a steam system follows.

STEAM SYSTEM OVERVIEW (REFER TO FIGURE A.1 ABOVE)

A steam system can be divided into four distinctive areas:

- generation
- distribution
- end-use
- condensate recovery

Generation

Boiler

Feedwater (8) is transformed into vapor or steam (12) in the boiler (10). Most packaged boilers are classified as either water-tube or fire-tube. In a water-tube boiler, water flows inside a series of tubes that are externally heated by combustion gases. A fire-tube boiler is oppositely configured—water flows outside a series of tubes, which are heated internally by combustion gases. In the boiler, a mixture of air (7) and a chosen base fuel (9) such as natural gas, fuel oil, coal, etc., supports combustion.

A boiler's air/fuel ratio is optimal when the amount of air mixed with the fuel is neither too little nor too much. If the air/fuel mixture does not have enough air (i.e., oxygen), incomplete combustion occurs. On the other hand, if the air/fuel mixture has too much air, the combustion becomes inefficient and stack temperature rises. This reduces the efficiency of the boiler because energy that could have been used to heat the water in the boiler is used instead to heat the excess air.

Since it is impossible to supply the precise volume of air needed for combustion, it is generally recommended that a small amount of excess air should be available to the boiler to ensure that complete combustion takes place.

Burner Management

Safety is a priority in boiler operation. The burner management system ensures the safety of the boiler and burner, monitoring such items as the flame, fuel pressures, temperatures, water level, etc. In addition, these systems are often designed to do other repeatable functions for the operator, including start-up and shut-down sequences.

Combustion Control

The separate purposes of the combustion control system and the burner management system can be a source of confusion. As stated, burner management is a safety system that monitors the burner; combustion control is the process of continuously regulating the flow of air and fuel to meet the demand for steam. The combustion control system is common to all steam generators, and the following control methods are used:

- single-point positioning
- parallel positioning
- metering
- steam flow/air flow

A single-point positioning combustion control system is the simplest type available. Interpreting a drop in boiler head pressure as a demand for steam, it increases the supply of air and fuel through a single mechanical device. Single-point positioning is the least costly system and, with characterizing fuels, provides an acceptable mixture of fuel and air.

Parallel positioning also responds to a drop in boiler steam pressure, but it controls the air and fuel supply separately. Unlike single-point positioning, this method allows for adjustments to the air/fuel mixture. However, since the relationship between the air and fuel is constant, the method cannot be fully optimized to match the ideal air/fuel ratio.

A metering system measures the fuel and air and properly mixes them for the combustion process. The most efficient method of control, it can even tie together the responses of multiple controllers, thus allowing one boiler to respond to a supply failure in another unit. It also prevents one boiler from getting too far ahead on the air/fuel ratio when a change in demand is experienced. These systems are normally used in plants that want to achieve the highest possible combustion efficiency.

A steam-flow/air-flow combustion control system is used when fuel cannot be metered and when the fuel energy content changes, such as with wood or coal. This system measures the steam output and airflow and mixes the fuel and air to achieve a high combustion efficiency.

An oxygen trim system can be added as an additional loop to any of the above systems. This loop measures the amount of oxygen in the flue gases (11) leaving the boiler and produces a signal that is compared to a predetermined set point. The system then adjusts the air supply to maintain the optimal air/fuel ratio for that particular boiler load. According to Nebraska Boiler Company, more oxygen is generally appropriate at very low loads (10% or more) but only 2-3% at full load.[30]

Blowdown

Solids, either suspended or dissolved, are always present in water. High levels of total dissolved solids (TDS), which eventually become sludge and settle in the bottom of a boiler, can both lower the boiler's heat transfer capabilities and cause significant damage to the unit. High levels of TDS also lead to foaming and carryover of liquid water into the steam supply. This reduces the efficiency of the system and can lead to water hammer, which may damage pipes, control valves, steam traps, and end-use equipment.

Solids are removed from the boiler by a process known as blowdown (19). There are two types of blowdown: bottom and surface.

Bottom blowdown is a manual process to remove the dissolved solids that have accumulated on the bottom of the boiler. The procedure is performed at regular intervals according to the type of boiler and steam and water usage.

Surface blowdown, also known as top blowdown, removes solids that are floating on or near the surface of the water in the boiler. Boilers have a metered opening just below the water's surface; high pressure inside the boiler forces or blows hot water (and the TDS) through this opening. There are three types of surface blowdown: intermittent, continuous, and automatic.

Intermittent blowdown is performed manually at intervals determined by the operator. The interval should be based on the amount of TDS in the boiler water, which can be very difficult to determine. Intermittent blowdown is recommended for boilers with low concentrations of TDS and/or with very minimal use of makeup water (1).

Continuous blowdown is normally done on boilers that have water with high concentrations of TDS. As the name implies, a small amount of water is continuously blown from the boiler to keep dissolved solids at acceptable levels.

---

[30] Nebraska Boiler, www.neboiler.com.

All blowdown procedures remove hot water and, therefore, energy from the steam system. This causes a decrease in total energy efficiency. Removing more water than is necessary to control TDS wastes energy and also money if water treatment chemicals are unnecessarily removed. In order to reduce these wastes and improve steam reliability, an automated blowdown system can be installed to optimize the interval and quantity of blowdowns. The automated system consists of controls, an automated valve, any necessary piping, and equipment that indicates TDS levels based on some measurement, such as the conductivity or relative density of the water.

The quantity of TDS in the water and/or the amount of makeup water used determines whether the blowdown should be intermittent, continuous, or automated.

Blowdown Heat Recovery

To further reduce the energy lost due to required blowdown, some type of blowdown heat recovery (18) process can be used. This will generally include two methods of recovery: heat exchanger and flash steam generation.

To recover the heat content of the water, a heat exchanger must be used. The water itself, which cannot be recirculated because of its high TDS content, is sent to the sewer (21). The conditioned water (20) is heated by the heat exchanger and sent to the deaerator system (5) to be part of the feedwater (8) supplied to the boiler.

Because the pressure inside a boiler is high, the water near its surface is at a temperature well above the point at which water would evaporate at normal atmospheric pressures. When this water is removed from the boiler, it experiences a tremendous drop in pressure, which immediately converts some of the water into steam in a process known as "flashing." This is dangerous if not handled correctly, but it also presents a second opportunity for energy recovery from surface blowdown. If this water is released into what is called a flash system, the heat/energy is captured in the form of low-pressure steam (16). This steam is free of TDS and can be returned to the deaerator system or used in a low-pressure steam end-use application.

Deaerator System

Feedwater is provided to the boiler from the deaerator system. Water enters the system from different sources including makeup water, hot water (17) from blowdown heat recovery, and condensate return (22). Before the water enters the boiler, all dissolved gases are removed to minimize corrosion. This process requires energy that is usually supplied by injecting some of the steam (6) produced by the boiler and/or low-pressure steam flashed from blowdown heat recovery.

Deaerators can use an atmospheric tank or a pressurized tank. One advantage of a pressurized tank is that condensate can be returned at a higher pressure and temperature, which reduces the amount of energy needed at the boiler to generate steam. The higher temperature also reduces the amount of dissolved gases in the water.

When a pressurized tank is used, deaeration takes place in two stages: the first stage is a spray assembly; the second stage will use either an atomizer or trays. Atomizer or spray-type deaerators use a high-velocity steam jet to remove gases. Tray-type deaerators use agitation created by spilling the water over several stacked plates usually arranged in a staggered pattern.

Stack Heat Recovery

Steam absorbs most but not all of the heat generated during combustion. Over 20% of it is normally exhausted from the boiler through the stack. (As discussed earlier, more heat is exhausted as the quantity of excess air is increased). A stack heat recovery (2) device can capture much of this energy, which is frequently used to heat water or air. There are three types of heat exchangers commonly used for stack heat recovery:

- economizer (pre-heating makeup water)
- air pre-heater (heating boiler combustion air)
- condensing-type economizer (heating process water)

An economizer is used to pre-heat makeup water that is needed because of system losses from blowdown and condensation. There are three different ways to position an economizer: in series prior to the deaerator (as shown in Figure A.1 above); in series between the deaerator and the boiler; or in parallel with the deaerator providing constant flow between the two.

An air pre-heater raises the temperature of the boiler combustion air so that less energy from the boiler is needed to heat the air. Both an air pre-heater and an economizer will reduce stack temperature; however, it is important that stack temperature remains hot (commonly above 300°F) to avoid condensation of gases that could produce acids that might damage the stack.

The use of condensing-type economizers is restricted to facilities that use high volumes of hot water for processes such as sterilization and equipment cleanup. Because of the volume of water that is heated, stack temperature will be dramatically reduced, causing condensation. This condensate is corrosive and could destroy standard stack materials. Therefore, special materials and a bypass are used in conjunction with a condensing-type economizer. The bypass is necessary to protect the special materials from damages caused by high stack temperatures.

Stack heat recovery systems can improve boiler efficiency as much as 15%.

Clean Heat Transfer Surfaces

It is normal for heat transfer surfaces to become fouled over time. Inside of a boiler, both the fire and water sides can be affected by the accumulation of dirt. The accumulation acts as an insulator, thus reducing heat transfer and wasting energy. In a fouled boiler, the wasted heat increases stack temperature. Heat exchangers like economizers can accumulate dirt, which also impacts efficiency.

Distribution

The distribution system is responsible for carrying the steam from the boiler to the end-use equipment in the plant. The distribution system must be properly designed to account for condensate drainage, system pressure, and flow control.

Support

All steam supply and condensate return pipes should be properly supported, guided, and anchored, allowing for expansion of the pipes due to temperature changes. A structure that is too tight can deform pipes and cause leaks.

Steam Traps

As steam moves throughout the system, it changes temperature, causing some condensation. Condensate may produce pipe hammering and can damage equipment by producing rust. Air can also cause condensate to form.

Steam traps (13) are automatic valves that separate air and condensate from the steam. A leaky trap wastes energy by allowing steam to enter the condensate return or by not expelling the condensate from the steam line, which reduces the efficiency of the system. Traps are classified into three main groups—mechanical, thermostatic, and thermodynamic—and there are several different types of traps in each group.

Because the traps function in different ways, sizing, positioning, and installation procedures vary, so attention must be paid to manufacturers' instructions. For example, some traps must be installed with the outlet pointing upward.

Safety Relief Valves

Safety relief valves (14) are placed on steam systems to protect components from damage caused from excessive pressure build-up in steam using equipment (15). These valves are often placed near the end-use equipment that it protects. For proper installation of pipes and relief vales, ASME B31.1—Power Piping code should be followed.

Insulation

As the temperature of the steam in the distribution system drops, it wastes energy. While some temperature drop is unavoidable, effectively insulating vessels, steam lines, valves, and even condensate return lines can help to reduce energy losses.

Condensate Recovery

The condensate recovery system is responsible for capturing the condensate present in the steam system and returning it to the deaerator system. The water quality of condensate is high enough for reuse in the boiler. Because its temperature is relatively high compared to cold makeup water, it requires much less energy to be reconverted into steam. In addition, it does not contain high TDS levels and does not require additional chemical treatment. As much condensate as is practical should be returned to the deaerator system. It can be recovered from processes, drips, or the steam lines (tracers) used to keep product from solidifying or freezing. Although drips and tracers generate relatively small amounts of condensate, they should not be neglected.

More information about the basics of steam systems is widely available. Refer to the list of resources at the end of this chapter.

ENERGY SAVINGS OPPORTUNITIES AND RELATED BEST PRACTICES

Since over 45% of all fuel burned by U.S. manufacturers is used to generate steam, proper management of this system is an important part of an effective EM system. The following paragraphs describe various factors that present opportunities for energy savings; where available, the accepted best practices associated with each factor are also given.

Supply

Correct Sizing of Boilers and Operating at High-Efficiency Firing Rates

Boilers differ in efficiencies due to model differences, type differences, etc. Food processors should identify the efficiency of their boilers and determine at what firing rates the efficiency peaks. Once this is known, the equipment can be set up for optimal use. Automatic controls can be installed to monitor the temperature and pressure of the system and control it accordingly.

The size of the boiler should be carefully considered. Oftentimes, companies purchase units that are capable of producing much more steam than the company needs. Short cycling occurs when oversized boilers quickly meet the demand for steam. The equipment becomes idle for a relatively long period of time, which leads to decreased energy efficiency. Operating boilers at very low rates also reduces efficiency, since some losses are fixed independent of the amount of steam produced.

Consider an example from Tip Sheet #16 of the U.S. Department of Energy (DOE), “Improving Steam System Performance: A Sourcebook for Industry.” In this example, a large boiler with a cycle efficiency of 72.7% (E_1) is substituted with a smaller boiler with 78.8% (E_2) cycle efficiency. The fraction of fuel saved can, therefore, be calculated as follows:

$$Fraction\ Fuel\ Savings = \left(1 - \frac{E_1}{E_2}\right) \times 100 = \left(1 - \frac{72.7}{78.8}\right) \times 100 = 7.7\%$$

As seen above, savings from operating a boiler at its best efficiency can be extremely valuable.

DOE's Industrial Technologies Program offers free software programs that allow users to assess current steam systems and potential energy saving improvements. These are available at the DOE Best Practices webpage.[31]

Air/Fuel Ratio

Inexpensive equipment is available that can determine the amount of excess air in combustion by measuring the contents of flue gases. DOE recommends such an investment for boiler systems with annual fuel costs above $50,000. Equipment that measures oxygen is more precise than carbon dioxide measuring devices. Information from the combustion analysis equipment is used to calibrate the settings on the air and fuel supply systems.

Periodic testing and adjustments to the burner are recommended to increase boiler efficiency. Contact the burner manufacturer for safety procedures and instructions before doing adjustments, and always adhere to applicable codes. Common practice is to test and adjust at two points only, a high- and low-firing rate, but this usually results in inefficient combustion at intermediate rates. The best practice is to adjust the burner at several different points along the air/fuel ratio curve.

In modern boilers, excess air should be set to approximately 10% (2.2% oxygen). This will vary from boiler to boiler and from application to application; always consult the boiler manual. Reducing excess air reduces stack temperature, as explained earlier. A widely used rule of thumb for estimating energy savings is that for every 40°F reduction in stack temperature there will be a corresponding increase in boiler efficiency of 1%.

Turbulators

In a fire-tube boiler, combustion gases usually pass back and forth multiple times. Since the water has more opportunity to absorb the combustion heat before it's exhausted, the overall efficiency of the boiler is increased. However, this also creates a problem. The turbulence of the exhaust gases becomes less intense on the later passes, allowing layers to form with the coolest layers to the outside nearest the tubes' surfaces. As a result, heat transfer is less efficient.

A device known as a turbulator can be used in multi-pass fire-tube boilers to increase the efficiency of heat transfer between the combustion gases and the surfaces of the tubes. Turbulators are available in different designs, including small baffles, twisted metallic strips, or steel coils that are inserted in the tubes. Heat transfer is enhanced when these devices reintroduce turbulence to the flow of the gases, breaking up the laminar boundary layer of gas near the tubes' surfaces. Turbulators are normally installed on the last pass where the gas flow is most laminar.

Turbulators are not yet widely accepted in the marketplace, but DOE has issued a bulletin that recommends that they be considered for two- and three-pass fire-tube boilers. Because turbulators can increase the heat absorption from combustion gases and thereby

---

[31] U.S. DOE ITP Best Practices, http://www.oit.doe.gov/bestpractices/.

lower stack temperatures, DOE touts them as "a substitute for a more costly economizer or air-preheater. They are simple, easy to install and low cost." DOE documents the case of a manufacturing facility that installed turbulators into their fire-tube boilers and reduced stack temperature by 140°F, improving boiler efficiency by 3.25% and reducing fuel costs by 4%.[32]

Boiler Room Ventilation

As previously stated in a description of air-fuel ratio, air is a basic element in combustion. Improper ventilation in the boiler room may lead to oxygen starvation in the burner, which results in incomplete fuel combustion. The commonly accepted process for calculating the amount of air required for boiler room ventilation is:

- determine the maximum burner CFM (flow rate) requirement for each boiler
- add all boilers' CFM requirements
- total required CFM X 1.1 = required CFM for the boiler room ventilation

This process does not take into consideration any other co-located applications (e.g., air compressors) that could add to the required amount of intake air. Always consult local codes that may supersede this recommendation.

Note that sufficient air is frequently provided through open doorways. However, during inclement weather, personnel frequently close these openings in order to maintain a workable room temperature. This can starve the boiler, upsetting the air/fuel ratio and dramatically reducing efficiency. Improper ventilation is usually noticeable in doorways where fast airstreams enter the room from adjacent areas. This airflow is caused by a negative pressure buildup when more air is exhausted through the stack than is brought into the boiler room.

Proper room ventilation affects energy usage by ensuring sufficient oxygen is available for complete fuel combustion. When the air supply is insufficient, combustion is incomplete or burners must run longer at higher firing rates to provide the needed steam.

Preheating Boiler Intake Air

All air that is used in the boiler is raised to combustion temperature. This requires energy that could otherwise be used to heat the water in the boiler. For this reason, it is a best practice to preheat the combustion air by absorbing heat that is otherwise wasted. This is commonly done through an air-to-air heat exchanger on the exhaust stack, or simply by collecting air from a warmer location, such as the air close to the ceiling. However, special attention must be taken to the capacity of the burner fan and to readjusting the air/fuel ratio. Warmer air is less dense and therefore caries less oxygen per volume. Thus, as air temperature increases, the fan will have to blow more air to the burner to keep the necessary oxygen.

---

[32] "Consider Installing Turbulators on Two- and Three-Pass Firetube Boilers," U.S. Department Of Energy, Steam Tip Sheet #25, April 2004.

Preheating boiler intake air is usually economically feasible for large water-tube boilers because some changes to the burner fan may be necessary. On smaller boilers, the cost of these component changes usually extends the payback period beyond acceptable limits.

A common rule of thumb is that every 40°F increase in air intake temperature yields approximately 1% in boiler efficiency improvement.

Burner Fan Motors

Installing premium efficiency motors and variable frequency drives (VFD) on burner fan motors may significantly reduce energy consumed by the boiler. Refer to the motors appendix of this document for more details.

Burner Management

Because the burner management system is so important to boiler room safety, a thorough audit of all boiler safety devices should be performed at least once a year. Furthermore, this system should be independent and not be used for other purposes such as combustion control.

Steam Pressure

Reducing steam pressure can reduce energy usage, maintenance costs, and labor costs. At low pressures, there is a decrease in leakage and losses due to transportation resistance. In addition, the steam is also at a lower temperature, thus there is a direct savings of energy. The reduction in steam leakage due to a reduced flow rate and pressure saves energy and makeup water costs. Makeup water costs can be significant because of water treatment expenses.

Decreasing steam pressure (and therefore temperature) also reduces heat transfer losses during steam distribution. If the change means that an operator needn’t be present in the boiler room at all times or if a lesser-ranked worker can be substituted, there may be labor cost savings as well. Valves and pipes are less stressed at lower pressures, which can result in reduced maintenance costs.

Pressure should be reduced to the minimum allowed by the boiler and plant equipment. Remember to consider line losses when finding the minimum allowable pressure for the system. For safety reasons, it is important to refer to the boiler manufacturer’s documentation before adjusting the minimum boiler pressure.

Deaerators

The deaerator supplies water to the boiler as feedwater. Feedwater temperature is important because raising feedwater temperature 6°C results in a savings in boiler fuel of approximately 1%. A tray-type deaerator is the most energy-efficient deaeration system and should be used whenever possible.

Whenever there has been a significant change to the steam system, like the addition of end-use equipment, increased condensate return, or heat recovery energy conservation measures, it is important to re-examine deaerator steam requirements.

Installation of continuous dissolved oxygen monitoring devices will help to identify operating practices that result in poor oxygen removal.

Minimizing Blowdown

As much condensate as possible should be recovered to reduce the volume of makeup water needed. Amount and frequency of blowdowns is dependent on the quantity and condition of the boiler makeup water. The blowdown rate normally should not be over 1-3% of the steam output.

Because bottom blowdown is performed manually, this type of procedure can only be improved by observing the content of the water drained. If the water drained does not contain impurities, the procedure can be done less often, until an optimal frequency is found for the plant. Heat recovery is not feasible on bottom blowdown systems.

The correct time interval between intermittent blowdowns should be determined using the aforementioned process for minimizing bottom blowdown.

The blowdown should be performed in such a way that the TDS level is kept to its maximum allowable value. Wulfinghoff's Energy Efficiency Manual provides an equation for approximating the amount of blowdown as follows:

$$Blowdown\ rate = Makeup\ rate \times \frac{TDS\ of\ Feedwater}{TDS\ in\ Boiler\ -\ TDS\ of\ Feedwater}$$

Automatic blowdown should be used whenever feasible to save energy on reducing blowdowns and also for better heat recovery.

Heat Recovery from Blowdown

Heat recovery is more efficient with continuous and automatic blowdown systems. If the correct equipment is used, up to 78% of the heat can be recovered. Heat can be recovered from the water and the flash steam.

To recover the heat content of the water, a heat exchanger must be used since TDS is present. Water heated on the heat exchanger can be sent to the deaerator tank to become part of the makeup water. For collecting the steam portion, the blowdown must be dumped in a flash tank where a portion of the water is flashed to steam. The flashed steam may be directly taken to the deaerator tank since it is free of TDS.

The Industrial Assessment Center program has shown energy savings of approximately $3,800/year on a 400-hp fire-tube boiler with automatic blowdown system for heat recovery.

Heat Recovery From Stack Flue Gases

When possible, heat from the stack should be recovered. An economizer can efficiently recover wasted stack heat and transfer it to boiler makeup water. As mentioned before, an increase of water temperature of 6°C results in a savings in boiler fuel of approximately

1%. For air pre-heaters, an increase of air temperature of 40°F results in an increase of boiler efficiency of 1%.

Condensing economizers require more changes and cost more but can provide about 10-15% increase in boiler efficiency.

Clean Heat Transfer Surfaces

Heat transfer surfaces should be cleaned periodically. Cleaning intervals depend on individual systems based on the boiler type and amount of makeup water used. Boiler water sampling can detect fouling on the water side. It is recommended that surfaces be cleaned at least once a year. Correct blowdown and water treatment will aid in keeping the water side surface clean. Insufficient blowdown will increase the amount of dirt in the steam system.

Monitor Fuel Usage and Document Price

Documentation is a critical component of improving energy efficiency. Factors to document include type of fuel, cost, amount used, operating steam pressure, and feedwater temperatures. Auxiliary systems (pumps, fans, etc.) can also be included for calculating the base price, which is normally based on 1,000 pounds of steam.

The following suggestions will make the documentation process easier and more efficient:

- Keep track of and document information related to the quantity and cost of fuel as well as quantity of steam (if possible).
- Keep a log of air/fuel ratio tests and adjustments to the burner.
- Build a pressure and load schedule; this is important when trying to set up the system to maximize boilers' efficiency.

The following equation can be used to find the cost of 1,000 pounds of steam based on the cost of fuel:

$$\text{Steam Cost} = \frac{A}{B} \times 1,000 \times 1,006 \times \frac{100}{E}$$

Where:

A = cost of fuel per therm
B = conversion constant, Btu per therm (100,000 for natural gas)
E = boiler efficiency

Information does not serve any purpose if not used. Examine the data on air/fuel ratio tests and adjustments to the burner, looking for ways that best practices can be applied to improve the system. The log can also be used to find problems in the system by tracking data that indicate the system is behaving unpredictably. Look for the likely causes of such data.

Distribution

Proper Use of Steam Traps

As with any device, traps fail with time. Periodic testing must be performed to find malfunctioning traps. Traps that are not serving their purposes can waste energy, negatively impact production, and damage equipment by allowing condensate or air to enter the product or by decreasing the temperature of the steam.

Testing of traps can be done in the following manner: ultrasonic testing, listening to audible trap sounds, checking condensate vents, opening test valves, visually checking using a sight glass, and measuring temperature differences.

Drip leg and steam trap stations should be installed at low points in the piping system, wherever pipes change direction, and at locations just upstream of valves that are normally closed.

It is estimated by DOE that systems not inspected during a three-to-five-year period will show about 15-30% of traps failed. A 1/8-inch trap on a 150 psig steam line can waste approximately $3,000/yr.[33]

Insulation

DOE's Industrial Technologies Program offers free software on choosing proper insulation material and thickness. The software is called 3E Plus and is available at the Best Practices webpage.[34] A 100-foot section of inefficiently insulated or bare steam pipe can lose as much as 480 MBtu/year[35].

Insulation should not be limited to steam pipes. Joints, valves, tanks, and condensate lines should also be insulated, as they are also sources of heat loss.

Fix Steam Leaks

Needless to say, steam leaks are a waste of money. More importantly, high-pressure steam leaks can be very dangerous. Leakage is most common at joints, valves, fittings, or where a sealant is present. If water treatment is not good, corrosion can cause pipes to leak as well.

Leaks can often be detected visually or by the sound. In some cases, larger leaks are not immediately repaired simply because the operator thinks that the leak is not a leak but a normal part of the operation. In most cases, steam should not be visible in a plant, as it should be discharged in a return system.

Infrared scanners and ultrasonic equipment can help detect smaller leaks.

---

[33] "Inspect and Repair Steam Traps," U.S. Department of Energy, Steam Tip Sheet #1, June 1999. Example uses $4.50 per thousand pounds of steam.

[34] U.S. DOE ITP Best Practices, http://www.oit.doe.gov/bestpractices/.

[35] For uninsulated 2" pipe operating at 365°F or 150 psig steam pressure. Source, Plant Support and Evaluations, Inc.

Approximately $100/yr can be saved in energy alone by fixing a very small leak with steam pressure of about 120 psig. There are usually additional savings because fixing the leak reduces the amount of makeup water that must be added to the boiler and reduces the pressure drop (and temperature drop) in the system.

Return of Condensate

Annual savings for properly returning condensate to the boiler can greatly decrease the usage of fuel. DOE estimates that up to about 18% of fuel used to heat makeup water can be saved with this action. In most cases, condensate should be returned at the highest pressure possible. If a low-pressure steam use is available at the facility, condensate can also be flashed to steam. In all cases, it is beneficial to return condensate to the boiler even if it is at atmospheric pressure so that some heat and the water can be reused.

Make sure that the condensate return piping is correctly sized. It is normal for some flash steam, which has a larger volume than water, to be present on the return system. Condensate pipes should be sized to accommodate a water-vapor mixture.

Safety

Be proactive about safety matters. Don’t wait for accidents to happen before you make changes to enhance the safety features of your system. Install a reliable burner management system. Furthermore, follow codes and regulations regarding boilers, pressure vessels, and piping.

Be aware that in most cases your boiler inspector will not check your piping system unless it is close to the boiler. This does not mean that he considers the piping correct and safe. A good starting point for safety information is code B31.1 provided by the American Society of Mechanical Engineers (ASME).

RESOURCES

Printed Material

ASME B31.1, Power Piping.

Moran, M.J. and Shapiro, H.N., Fundamentals of Engineering Thermodynamics, John Willey & Sons, 4th ed., 1999.

Mull, T.E., Practical Guide to Energy Management for Facilities Engineers and Managers, ASME, NY, 2001.

Singh, R.P. and Heldman, D.R., Introduction to Food Engineering, Academic Press, 3rd ed., 2001.

Wulfinghoff, D.R., Energy Efficiency Manual, Energy Institute, MD, 1999.

DOE maintains an extensive listing of publications and articles that provide information on steam, related best practices, and standards. They are listed in categories and can be found at the following webpages:
Total Steam System: http://www.oit.doe.gov/bestpractices/steam/totalsteam.shtml
Generation: http://www.oit.doe.gov/bestpractices/steam/generation.shtml
Distribution: http://www.oit.doe.gov/bestpractices/steam/distribution.shtml
End use: http://www.oit.doe.gov/bestpractices/steam/enduse.shtml
Recovery: http://www.oit.doe.gov/bestpractices/steam/recovery.shtml

On-Line Tools

U.S. Department of Energy
Best Practices: www.oit.doe.gov/bestpractices
Steam tools and publications: http://www.oit.doe.gov/bestpractices/steam/tools.shtml

- Fact Sheets
- BestPractices Steam Reports
- Technical Briefs
- Industry Successes
- Steam Tips
- Case Studies
- Financial Tools
- Technical Tools
- Training
- Library
- Software
- Energy Service Companies/Assistance Centers

Software Tools: www.oit.doe.gov/bestpractices/software_tools.shtml

- Process Heating Assessment and Survey Tool (PHAST)
- Steam System Scoping Tool
- Steam System Assessment Tool (SSAT)
- 3E Plus – Insulation Thickness Computer Program

Energy Efficiency and Renewable Energy – Industrial Technologies Program

Energy Information Bridge: www.osti.gov/bridge

Energy Matters: www.oit.doe.gov/bestpractices/energymatters/energy_matters.shtml

Spirax Sarco Learning Center:
www.spiraxsarco.com/learn/default.asp?redirect=html/3_13_01.htm

Steaming Ahead: www.steamingahead.org

Organizations

Association of Energy Engineers: www.aeecenter.org

Boiler Efficiency Institute: www.boilerinstitute.com

Council of Industrial Boiler Owners (CIBO): www.cibo.org

Gas Research Institute: www.gri.org

Iowa State University Industrial Assessment Center (IAC): (515) 294-3080 or
www.me.iastate.edu/iac

United Kingdom Energy Efficiency: www.etsu.com

Appendix B. Lighting

OVERVIEW

According to the U.S. Department of Energy, artificial lighting can account for 10% to 20% of the energy consumed by industries. This estimation increases a few percentage points if the associated cost for HVAC is included. The Rocky Mountain Institute estimates that business can effectively save 70% to 90% of this energy cost by utilizing modern lighting technology.

In recent years, lighting technology has improved dramatically. The most used industrial lamp technologies can be divided into three main categories:

- incandescent
- fluorescent
- high-intensity discharge (HID)

Incandescent

Incandescent lights use a tungsten filament encapsulated by glass. The filament creates a resistance to the electricity that generates a high temperature creating visible light. Halogen lamps can also be considered in the same group. Incandescent and halogen lamps can also contain an inert gas in the glass capsule that increases lamp life. Incandescent lamps are not very energy efficient, since most energy is spent producing heat.

Fluorescent

In fluorescent lamps, only a gas (normally mercury) fills the glass capsule. Electrodes placed at the ends of the tube form an arc through the gas. However, the lighting generated by fluorescent lights is not the direct product of the arc. Most light is generated by phosphors coating the inside of the tube, which react to the radiation emitted by the arc generating light. In order to control the amount of current flowing through the lamps, fluorescent lights require the use of ballasts. Fluorescent lights are much more efficient than incandescent lights. However, not all energy used is transformed into light; some energy is used by the ballast and some is lost (mostly into heat).

HID

High-intensity discharge lights, different from incandescent and fluorescent, are not often used in offices. HID lamps are great for large, open areas like outdoor lighting and large facility illumination. HID lamps consist of three different varieties: mercury vapor, high-pressure sodium, and metal halide. HID lighting is produced by passing an electric arc inside a capsule (glass, quartz, or ceramic) containing a gas or vapor. The current flows between two electrodes located at opposite ends of the lamp. Unlike fluorescent lamps, the arc in HID is the main source of light. Phosphors can be added to the outer capsule to change the color of the light. The same capsule also blocks harmful ultraviolet radiation emitted by mercury vapor and metal halide lamps. It is important to note that the lamps can work approximately 100 hours without the outer protective capsule. Therefore, for safety purposes, these lamps should be well guarded and maintained. Whenever possible, high-pressure sodium lamps should be used outdoors as they do not emit harmful radiation.

HID lamps also require ballasts to control the current flow through the lamps. Mercury vapor lights are normally characterized by the blue color they emit. Mercury lamps are available up to 1,000 watts. High-pressure sodium lamps can be identified by their orange light; their power ranges between 35 and 1,000 watts. Metal halide lamps emit a whiter color and are available up to 1,000 watts. Metal halide lamps tend to have a shorter lifespan, approximately 20,000 hours, compared to high-pressure sodium and mercury vapor lamps, whose lifespan is about 4,000 hours longer.

When constructing or retrofitting a facility, all lighting types should be considered. The lighting selection should not be based only on visual effects or energy efficiency. The best lighting design will take both criteria into account for the selection. Most utility companies provide rebates for using energy-efficient technology. These rebates can significantly reduce the payback period.

ENERGY SAVINGS OPPORTUNITIES AND RELATED BEST PRACTICES

In 1,285 energy audits of food processors conducted by the national network of IACs, the following were the most significant energy-related topics with regard to lighting (significance is based on the combination of frequency of occurrence and dollars being lost):

- fluorescent lighting
- HID lighting
- occupancy sensors
- daylighting
- minimal illumination levels

Fluorescent Lighting

A best practice related to fluorescent lighting is to change conventional ballasts and T-12 lamps to T-8 lamps with electronic ballasts. A conventional T-12 lamp is easily identified by its larger diameter (1.5”). Because of new technology, electronic ballasts and T-8 lamps (1” diameter) provide more light per surface area. New electronic ballasts generate less flickering due to a higher operating frequency. If retrofitted, a system may reduce total power usage by 25-30%.

Energy savings will vary depending on the size of the facility. The following estimated savings are calculated for a facility with 500 four-foot-long conventional T-12 lamps and 250 ballasts, operational for 8,760 hours per year, having marginal energy cost at $0.03/kWh and marginal cost of demand at $75/kW-yr. For this example, typical cost savings in energy usage and demand are about $2,500 and $400 per year, respectively. There are also additional maintenance savings, since T-8 lamps are more durable.

High-efficiency HID Lighting

HID lighting can be very efficient in production areas. Using it will instantly decrease power usage with a negligible corresponding decrease in illumination level. Technology has both improved the lifespan of the lamp and increased system efficiency. High-efficiency HID lights use less power (wattage) and are designed as a replacement to conventional HID lamps, which eliminates the need to replace ballasts.

Reductions of approximately 10% of lamp wattage are very common. The most common lamp wattage in the industry is 400. 360-watt lamps can replace these lamps as they burn out. Note that low wattage replacements are available for nearly all lamp wattages using conventional HID ballasts.

Also available are pulse-starting HID systems, which consume even less electricity than high-efficiency HID but with virtually no reduction in illumination levels. However, in order to have a pulse-start system, the ballasts must also be retrofitted, thus making the change expensive. Pulse-starting technology should be considered when constructing an addition to an existing facility. Pulse-start lights with 320 watts can replace existing 400-watt HID fixtures with minimal reduction in lighting level.

Energy usage cost savings associated with changing 100 existing 400-watt lamps to 360-watt, high-efficiency lamps are approximately $1,250, having marginal energy cost as $0.03/kWh. Demand cost savings also associated are about $360, having marginal cost of demand as $75/kW-yr.

Occupancy Sensors

Numerous types of occupancy sensors are available for all lighting systems. The technologies most used to sense presence in a room are infrared and ultrasonic. Infrared sensors detect body heat from occupants and ultrasonic sensors detect movement. Infrared sensors are good for enclosed office areas and should not be used in areas with obstructed views. Therefore, infrared sensors should be avoided in restrooms. Ultrasonic sensors are recommended for areas where movement can be detected. Thus, they should be avoided in rooms with large air movement or open offices. Dual technology is available to activate lights only when both sensors detect occupancy. Detection sensitivity and time delay can be adjusted in most sensors. It is estimated that restrooms, offices, and meeting rooms could have the lights turned off 65%, 45%, and 50% of the time, respectively, due to regular occupancy.

Occupancy sensors may also be used with HID lights. Unlike fluorescent or incandescent systems, conventional HID lamps may require cool-down and warm-up times before they may be repetitively switched off and on. These times may add up to 15 minutes, depending on the lamp type. Therefore, in order to have HID lights on occupancy sensors, bi-level technology must be used so that the lamps are not completely shut off when an area is unoccupied. Bi-level controls allow ballast to operate at a fraction of the power when there is no occupancy, keeping them ready to be turned to full power when needed.

Energy usage cost savings for a conference room with 12 ballasts containing a total of 48 four-foot conventional fluorescent lights is approximately $100 per year. Many times, occupancy sensors are neglected because of the small annual cost savings. However, it is vital to bear in mind that these savings can add up to significant amounts as sensors are installed in several rooms. For this example, the office area for the facility would be occupied approximately 12 hours per day for five days a week with $0.03/kWh marginal cost of energy.

The aforementioned example indicates an energy usage cost savings of approximately $100 per year. However, there would also be a demand cost savings of approximately $85 per year. Demand cost savings were not considered for occupancy sensors, since it is hard to predict whether or not the lights would be shut off during peak demand.

Daylighting

Daylighting is the optimization of natural light to illuminate a room. According to DOE, the use of daylighting, in conjunction with energy efficient lighting technology, may reduce the power usage from artificial lighting by more than 50%. This reduction in energy usage does not affect the lighting level of the room. Sunlight is also considered a healthier light, thus it may improve worker productivity. Studies show that daylighting decreases the energy necessary to heat and cool a building. Daylight provides less heat to a room than artificial lighting, thus it saves energy when cooling is necessary. A well-designed sunlit office can also use solar energy to decrease the heating load on HVAC equipment during the winter. Daylighting alone does not save lighting energy; it must be used in conjunction with other technology. Dimming sensors should be installed in the lighting system to control artificial lighting levels according to available sunlight. A great number of daylighting technologies are available to enhance occupant comfort and transmission of natural light. Some easy changes can be done to existing buildings, like adding skylights, more translucent walls, or changing shading devices.

Minimal Necessary Illumination Levels

It is common to have excessive lighting levels in some areas of industrial facilities. The best practice is to measure existing lighting levels and make corrections accordingly. Minimum lighting levels should be set according to standards and not based on personnel opinion. It is also common to have areas unnecessarily lighted. Such areas can be enclosed offices within the production area that still have HID lighting on top, thus only illuminating its ceiling. The correction can be as simple as disconnecting a ballast. Furthermore, to decrease the amount of unnecessary illumination, task lighting can be used in the areas that need high lighting levels or special light color. When task lighting is installed, the overall lighting for the area should be reduced to maximize savings. Task lighting commonly uses efficient fluorescent lamps and ballasts and is frequently installed over workbenches and near machinery.

Disconnecting a 400-watt HID ballast that is normally functional without need for the entire year, can amount to approximately $150 in annual savings. Disconnecting several unneeded ballasts can greatly improve lighting efficiency in a plant.

RESOURCES

Printed Material

Boylan, B.R., The Lighting Primer, Iowa State University Press, 1st ed, 1987.

Chen, K., Energy Effective Industrial Illumination Systems, The Fairmont Press, 1994.

Fetters, J.L., The Handbook of Lighting Surveys and Audits, CRC Press, 1997.

Lindsey, J.L., FIES, Applied Illumination Engineering, Prentice Hall, 1991.

Lithonia Lighting, Industrial Lighting Guide, Quebec, 2000.

Martin, N., Worrell, E., Ruth, M., Price, L., Elliott, R.N., Shipley, A.M. and Thorne, J., Emerging Energy-Efficient Industrial Technologies, LBNL and ACEEE, 2000.

Phillips Lighting Company, Philips Lighting Handbook, 1984.

U.S. Environmental Protection Agency, Green Lights Program: Lighting Upgrade Manual, 4th ed, Feb. 1993.

Wulfinghoff, D.R., Energy Efficiency Manual, Energy Institute, MD, 1999.

On-Line Tools

American Council for an Energy Efficient Economy: www.aceee.org

Centre for Analysis and Dissemination of Demonstrated Energy Technologies (CADDET): www.caddet.org

U.S. Department of Energy, Energy Efficiency and Renewable Energy (EERE): www.eere.energy.gov

Energy User News: www.energyusernews.com

Lawrence Berkeley National Laboratory, The Energy Analysis Department: http://eetd.lbl.gov/EA.html

Sustainable by Design: www.susdesign.com

Technical Information Services: www.ntis.gov

Organizations

Alliant Energy: www.alliantenergy.com

Energy Center of Wisconsin: www.ecw.org

Energy Ideas: www.energyideas.org

Florida Solar Energy Center: www.fsec.ucf.edu

Illuminating Engineering Society of North America (IESNA): www.iesna.org

Iowa Energy Center: www.energy.iastate.edu

Iowa State University Industrial Assessment Center (IAC): (515) 294-3080 or www.me.iastate.edu/iac

Lighting Research Center: www.lrc.rpi.edu

MidAmerican Energy: www.midamericanenergy.com

Rocky Mountain Institute: www.rmi.org

Appendix C. Compressed Air

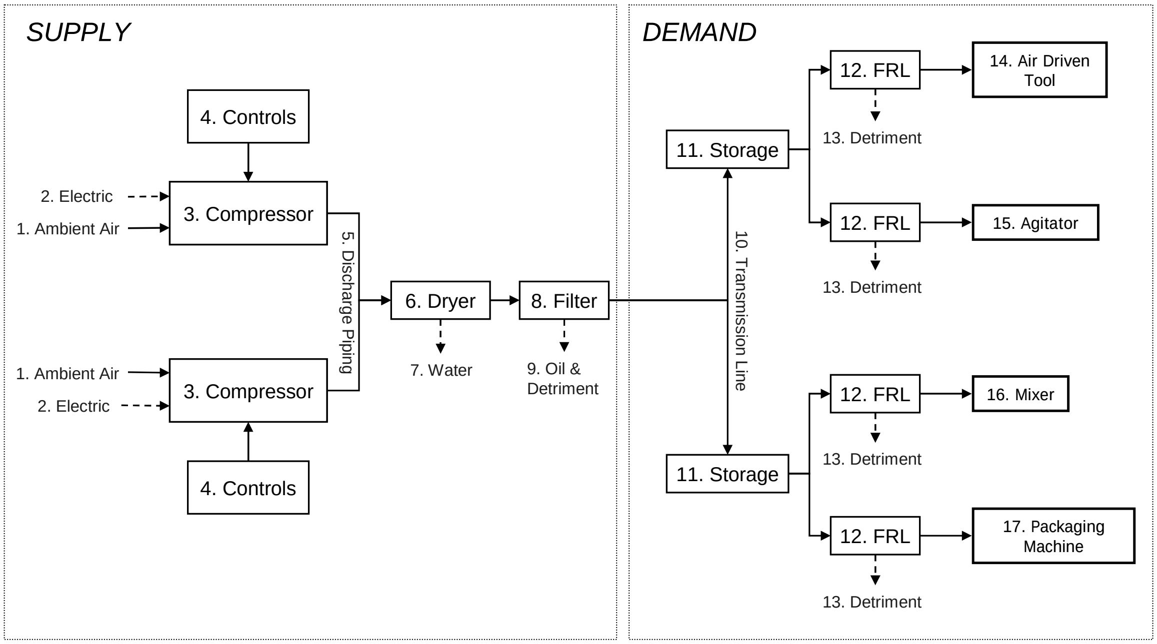


Figure C.1 – Compressed air system layout

SYSTEM OVERVIEW (REFER TO FIGURE C.1 ABOVE)

Compressed air systems are often operated 24 hours a day, seven days a week, 52 weeks of the year. Therefore, it should not be surprising that, according to the U.S. Department of Energy's Office of Industrial Technology (OIT), compressed air systems account for $1.5 billion in energy costs per year. OIT has also found that optimizing compressed air systems can improve energy efficiency by 20 to 50 percent!

A compressed air system has both a supply and demand side. The supply side consists of all of the equipment that conditions air, and the demand side is comprised of the remaining components. The primary components of a compressed air system, as shown in Figure C.1, are:

- compressor (3)
- controls (4)
- discharge piping and transmission lines (5 and 11)
- dryer (6)
- filter (8)
- storage tank (10)
- filter, regulator, lubricator, also known as FRL (12)
- compressed air-powered equipment (14-17)

The compressors (3) are the largest energy-consuming equipment in the compressed air system. Compressors are divided into two basic types: dynamic and positive displacement. Most industries use positive displacement compressors in the form of either reciprocating or rotary-screw compressors. Compressor controls (4) use many different techniques depending on the demand for the plant. Good controls are necessary for a well-managed system.

Because of the wide variety of business sizes and applications, air compressors used by food processors typically vary in power from 20 to 300 hp. The compressor is generally powered by a 460-volt A/C power source (1). Maximum pressure at the compressor also varies but usually ranges from 90 to 130 psi.

The ambient air (2) that is pulled into the compressor contains some amount of water vapor. Most of this water (7) is removed in the dryer (6) after the air is compressed. Moisture that remains in the system can cause equipment problems and decrease efficiency. Moist air can account for rust and scale build-up in transmission lines (11). It can also cause maintenance problems on equipment (14-17) or wash away important lubricants.

The filter (8) removes any oil and debris from the compressed air. A dirty line can increase pressure losses on the transmission lines (11) and damage equipment.

Storage tanks (10) can be located in many places throughout a plant. Many experts recommend placing storage tanks close to the compressors and close to major demand areas. These tanks help match the supply of compressed air to the demand for it throughout the system. They also reduce unnecessary start-up by buffering the compressors from fluctuations in system pressure caused by frequently changing demand at the points of usage.

A series of discharge piping and transmission lines, some fixed and many flexible, connect the air-driven equipment to the air supply. It is common to have the air passing through an additional FRL (12) before entering the various air-driven equipment.

ENERGY SAVINGS OPPORTUNITIES AND RELATED BEST PRACTICES

In 1,285 energy audits of food processors conducted by the national network of Industrial Assessment Centers, the following were the most significant energy-related topics with regard to compressed air systems (significance is based on the combination of frequency of occurrence and dollars lost):

- air leaks
- system pressure
- intake air temperature
- compressor size
- compressor lubrication

Demand

Air Leaks

It is important to educate employees on the costs related to air leaks and improper uses of compressed air. One type of compressed air "leakage" that is often overlooked occurs when compressed air is provided without regulating the pressure. Different pieces of equipment require different pressures, and supplying compressed air above the minimum necessary pressure causes excess air flow and wastes energy. If regulators are installed, they should be adjusted to the appropriate pressure.

The recommended best practice for dealing with air leaks and improper uses of air is to implement a continuous program for locating and fixing leaks as well as identifying improper and unregulated uses of compressed air. To avoid having unqualified plant personnel adjust pressure regulators to their wide open position, it is recommended to install them out of the easy reach of operators.

Savings in energy costs will vary depending on the size of the compressed air system in a given facility. The following estimated savings are calculated for a “base system” consisting of two 100-hp, screw-type compressors generating 120 psi line pressure and operating 24 hours, seven days a week, 52 weeks a year. Marginal energy cost is \$0.03/kWh, and marginal cost of demand is \$75/kW-yr. For this base system, typical savings in energy usage ranged from \$440 to \$1,100, while demand cost savings varied from \$1,560 to \$3,900 per year. Total cost savings, therefore, ranged from \$2,000 to \$5,000 per year.

Supply

System Pressure

Common practice is to set system pressure relatively high. This is usually done with the good intent of keeping up with demand. By increasing line pressure, however, compressors increase energy usage and also increase compressed air consumption. Air leaks exacerbate this problem. Insufficient airflow is normally not caused by a problem in the supply side of a compressed air system (see Figure C.1), but it is instead a demand-side issue. For example, incorrect pipe sizing can cause a loss of system pressure. In such a case, it is necessary to increase pipe size or reduce the number of sharp bends in the piping.

The most recommended best practice for dealing with system pressure is actually to decrease pressure by small increments of about 5 psi at a time. Continue to reduce system pressure until the performance of the air-driven devices is adversely affected. Then slowly increase pressure back toward the previous setting until the lowest set point is found for the plant.

For a reduction of 5 psi on the “base system,” estimated savings in energy usage are \$790 per year, while demand cost savings are \$225 per year. Total cost savings, therefore, are \$1,015 per year.

Intake Air Temperature

Colder air is more dense and, therefore, requires less energy to compress. Studies show that reciprocating compressors can realize significant energy savings if outside air is ducted directly to the compressor air intake. It is common to use PVC piping for this purpose. Note that this is not the same as ducting outside air into the compressor area where it then mixes with the ambient air before it enters the compressor. In most cases, this greatly warms the colder, outside air, negating most of the benefit.

In Iowa, for two 100-hp reciprocating compressors, estimated savings in energy usage are approximately $2,140 per year while demand annual cost savings are $540. Therefore, the total annual cost savings are $2,680.

Compressor Controls

It is common to find oversized compressors in plants. This unnecessarily increases electrical demand and energy consumption. The recommended best practice for determining whether the compressor is properly sized is to use an electrical device that logs the power usage at the compressor. The data collected will show the load pattern on the compressor, thus helping to determine whether it is oversized.

Instead of purchasing a new compressor, one can also deal with oversized systems by installing a sequencer controller to manage the supply of compressed air. As loads vary, sequencer controllers allow the system to match the demand by operating the best equipment available for the load.

Multiple compressors may also be set to load and unload at different pressures in a “cascading” fashion. For example, if all compressors are loaded and the demand for air drops, system pressure will rise. At a preset point, one of the compressors will unload and subsequently shut down if demand for air stays low. If system pressure continues to rise, a second compressor will follow the same sequence. When the demand for compressed air increases, system pressure will drop and the compressors will be engaged in the reverse order. Variable frequency drives can also be installed in an air compressor to allow it to slow down and speed up according to the demand of air. Therefore, the compressor can modulate the production of air as needed. VFDs are further explained in the motors section of this document.

For the reduction of a 150-hp to a 100-hp screw compressor, estimated savings in energy usage are approximately $4,800 per year, while demand cost savings are about $1,370 per year. Total cost savings, therefore, are $6,170 per year.

Compressor Lubrication

The recommended best practice for compressor lubrication is to use synthetic lubricants to reduce friction. This will reduce the energy required by the compressor and has the added advantage of extending oil life to about three to four times that of premium mineral oils.

For the “base system,” estimated savings in energy usage are approximately $1,780 per year, while demand cost savings are $510 per year. Total cost savings, therefore, are $2,290 per year. The additional cost savings from adopting synthetic lubricants that results from the longer lifecycle with the associated reductions in the labor and materials involved will vary with your maintenance practices.

RESOURCES

Printed Material

Galitsky, C., Worrell, E. and Ruth, M., Energy Efficiency Improvement and Cost Saving Opportunities for the Corn Wet Milling Industry, EPA, 2003.

Martin, N., Worrell, E., Ruth, M., Price, L., Elliott, R.N., Shipley, A.M. and Thorne, J., Emerging Energy-Efficient Industrial Technologies, LBNL and ACEEE, 2000.

Mull, T.E., Practical Guide to Energy Management for Facilities Engineers and Managers, ASME, NY.

Okos, M., Rao, N., Drecher, S., Rode, M. and Kozac, J., Energy Usage in the Food Industry, ACEEE, 1998.

Rollins, J.P. ed., Compressed Air and Gas Handbook, Prentice-Hall, Inc. 5th ed, 1989.

Talbott, E.M., Compressed Air Systems: A Guidebook on Energy and Cost Savings, Fairmont Press, 2nd ed, 1993.

On-Line Tools

Compressed Air Challenge: www.compressedairchallenge.org

Food Engineering: The Magazine for Manufacturing Management: www.foodengineeringmag.com

Ingersoll Rand. (2001). Air Solutions Group.Compressed Air Systems Energy Reduction Basics: www.air.ingersoll-rand.com/NEW/pedwards.htm

Lawrence Berkeley National Laboratory, The Energy Analysis Department: http://eetd.lbl.gov/EA.html

Office of Industrial Technology (OIT), Best Practices: www.oit.doe.gov/bestpractices

Office of Industrial Technology (OIT), Software Tools: www.oit.doe.gov/bestpractices/software_tools.shtml

Organizations

British Compressed Air Society: www.britishcompressedairsociety.co.uk

Council of Industrial Boiler Owners (CIBO): www.cibo.org

Food and Drink Federation, Voice of the UK Food and Drink Manufacturing Industry: www.fdf.org.uk/home.aspx

Iowa State University Industrial Assessment Center (IAC): (515) 294-3080 or www.me.iastate.edu/iac

Appendix D. Motors and Pumps/Fans

The U.S. Department of Energy estimated in a 1994 study that electrical motors in industrial facilities use roughly 23% of the electricity sold in the country. Motors are widely used by industry, and efficiencies have increased in recent years due to market pressure and regulations.

ENERGY SAVINGS OPPORTUNITIES AND RELATED BEST PRACTICES

The following paragraphs describe various factors that can result in energy savings; if available, the accepted best practices associated with each factor are also given. Motor upgrades should be considered since, in large applications, energy savings would quickly offset the initial investment.

Power Factor

Motor windings require both magnetizing current as well as the work-producing current that is used to drive the equipment. The power factor is the ratio of the work-producing current to the total current (work-producing plus magnetizing). It’s an important component of controlling energy costs because, when it’s too low, utility companies may assess reactive demand charges. (See the energy cost structure chapter for more details.) Installing capacitors is a simple and effective way to bring the power factor near 1.0, thus eliminating reactive demand charges.

Motor Efficiency Upgrades

Always consider purchasing the most efficient motor available when replacing an existing motor. Energy-efficient motors can cost 10-20% more than standard motors but energy savings normally offset this cost in less than two years. Oftentimes, motors are replaced by low-efficiency equipment because a fast work order is needed. To ensure the availability of energy-efficient equipment, make advanced purchases of replacement motors for equipment that tends to fail.

Motor Sizing and Loading

Most industrial motors are most efficient when running from 65% to 100% of the rated power. The maximum efficiency is normally 75% of the load. Most motors tend to dramatically lose efficiency at loads below 50%. Power factor also deteriorates as loads decrease. Motors are considered underloaded when running below 65% load. On the other hand, motors are considered overloaded when running for long periods of time above their rated power. Overloaded motors will overheat and lose efficiency. Consider replacing all motors operating constantly below 40% or at any point above the rated load.

In many cases, motors are oversized because of safety factors incorporated during the design stage. All systems, including pumps, fans, and compressors, are designed to accommodate changes in the system, but designers should size motors to run within the best efficiency band (65-100% of the load). In the cases of fans and pumps, impeller sizes can be changed to better fit the load and accommodate a change in the process without having to purchase new equipment. VFDs or variable speed motors can accommodate changes in the load as well. Following are some opportunities for reducing the load requirements on the system:

- Eliminate bypass loops and unnecessary flows.
- Increase pipe diameter to reduce friction.
- Use holding tanks to better match pumping flows and production requirements.
- Reduce equipment (e.g., pump, fan, etc.) size to match load.
- Install parallel systems for varying loads.
- Reduce system pressure.

<u>Pumps and Fans in Parallel or in Series</u>

Pumps and fans can be arranged in series or in parallel in order to provide sufficient pressure or flow rate. When the necessary flow is not achieved with a single pump or fan, an additional pump or fan can be installed in parallel to the existing equipment, thereby increasing the flow rate and eliminating the need to install a much larger pump or fan.

On the other hand, when the desired pressure is not achieved, an additional pump or a booster fan can be installed in series. This action increases the pressure provided by the equipment, eliminating the need to install a larger pump or fan for the entire system.

Furthermore, when a system utilizes multiple pumps or fans in parallel, motor speed can be controlled in one of the motors to effectively manage the flow.[36] For example, when two pumps are operating in parallel, a VFD can be installed in one. The VFD enables this pump to reduce its speed as the demand for flow is reduced. If this pump speed is reduced to its minimum, the other pump can be shut off and the controllable pump can speed up again. In this way, the necessary amount of fluid can be pumped without wasting energy.

<u>Control Motor Speed</u>

Motor speed controls should be considered for any application that has variable loads. In many variable load applications, such as cooling tower pumps, a mechanical device like a throttling valve is used to control flow. These devices can reduce flow, but they will not significantly reduce energy consumption. According to commonly used fan laws, the required fan power[37] varies as the cube of the rotational speed and the volume flow rate[38] (CFM) delivered varies directly with the speed. Therefore, substantial energy savings can be achieved if motor speed is controlled. Changing the voltage supply will control the speed of DC motors. In contrast, AC-motor speed control can be achieved with

- multi-speed motors
- multi-motor drives
- VFD or variable speed drives

For the most part, multi-speed motors are equipped with dual speeds. They are simple to use and relatively inexpensive, but their ability to improve efficiency is limited. For

---

[36] More information on motor speed control can be found in the control motor speed section.

[37] $FP_2 = (RPM_2/RPM_1)^3 \times FP_1$ where: FP = Fan power and RPM = Fan speed.

[38] $CFM_2 = (RPM_2/RPM_1) \times CFM_1$ where: CFM = Fan air delivery and RPM = Fan speed.

applications with varying load levels, much greater gains in efficiency can be realized with VFDs.

Multi-motor drives, commonly seen in cooling tower fan operations, utilize more than one motor with different speeds to control a single application. Because these motors are of different speeds, they allow for a wide range of configurations for the application. In cooling tower applications, it is common to see two motors connected to a single shaft. The motors operate separately depending on the speed needed for the fans.

Unlike the other applications, a VFD can be installed to ordinary AC motors to control the frequency of the current. A VFD can precisely control the speed of the application, making it energy efficient. Therefore, VFDs are, in many cases, the best option for speed control. An application controlled by a VFD wastes some energy since heat is formed from the transformation of the current; this loss depends on the speed reduction and the motor load. A VFD cannot reduce the speed of the motor to near zero.[39] The drive has limitations as to the maximum allowable frequency reduction. On fan and pump applications, the VFD normally is set to control a constant pressure for the system, thus it modulates speeds according to the flow but keeps constant pressures.

Voltage Unbalance

Voltage unbalance occurs when there are different voltages on the lines of a polyphase motor. This leads to vibrations and stress on the motor as well as overheating and reductions in shaft power. It is recommended that the electrical distribution system be checked for voltage unbalances in excess of 1%. Polyphase motors with unequal voltage supplies lose efficiency. The losses are drastic for unbalances beyond 1%. According to the DOE,[40] common causes of unbalances include:

- faulty operation of power factor correction equipment
- unbalanced or unstable utility supply
- unbalanced transformer bank supplying a three-phase load that is too large for the bank
- unevenly distributed single-phase loads on the same power system
- unidentified single-phase to ground faults
- an open circuit on the distribution system primary

Maintenance

A well-controlled and well-documented maintenance program can identify problems before they happen. Check regularly for noise and vibration as well as motor temperature. Always use good quality oil for lubrication and follow manufacturers' instructions.

Power Transmission

Transmission equipment such as gears, belts, and shafts should be properly maintained to remain efficient. Common V-belts tend to slip on drive sheaves. Therefore, notched V-

---

[39] VFDs have a limited maximum speed reduction allowed that is in the range of 40% to 50%.

[40] Motor Tip Sheets, Eliminate Voltage Unbalance, www.oit.doe.gov/bestpractices/pdfs/motor2.pdf.

belts should be used instead. They offer more friction during operation and still allow for startup slippage. Some manufacturers estimate about 3% losses from standard V-belts. Notched V-belts also tend to run cooler and for longer periods of time. Chains or gears can reduce losses even further. However, worm gears should only be used in small applications with motors smaller than 10 hp.

RESOURCES

Printed Material

McCoy, G.A. and Douglass, J.G., Energy Management for Motor-Driven Systems, U.S. Department of Energy, Motor Challenge Program, rev. 1, 1997.

McQuiston, F.C., Parker, J.D., and Spitler, J.D., Heating, Ventilating, and Air Conditioning: Analysis and Design, Willey & Sons, 5th ed., 2000.

O'Callaghan, P.W., Energy Management, McGraw-Hill, 1993.

Wulfinghoff, D.R., Energy Efficiency Manual, Energy Institute, MD, 1999.

On-Line Tools

U.S. Department of Energy
Energy Efficiency and Renewable Energy – Industrial Technologies Program
Energy Savers: www.eere.energy.gov/consumerinfo
Best Practices: www.oit.doe.gov/bestpractices
Motors: www.oit.doe.gov/bestpractices/motors

- Motor Tip Sheets
- Motor Efficiency Case Studies
- Technical Publications

Software Tools: www.oit.doe.gov/bestpractices/software_tools.shtml

- MotorMaster+ 4.0
- MotorMaster+ International

Energy Information Bridge: www.osti.gov/bridge
Energy Matters: www.oit.doe.gov/bestpractices/energymatters/energy_matters.shtml

Energy Services, Energy Solutions Database: www.energyexperts.org/energy_solutions

Bonneville Power Administration: www.bpa.gov

Alliance to Save Energy: www.ase.org

Organizations

Alliance to Save Energy: www.ase.org

The Carbon Trust: www.thecarbontrust.co.uk/energy

Iowa State University Industrial Assessment Center (IAC): (515) 294-3080 or www.me.iastate.edu/iac

National Electrical Manufacturers Association: www.nema.org

Appendix E. Resources

PRINTED MATERIAL

Aro, T. and Koivula, K., Learning from Experiences With Industrial Ventilation, CADDET, Sittard, Netherlands, 1993.

ASHRAE Standard 62, Ventilation for Acceptable Indoor Air Quality.

ASHRAE Standard 15-1992, Safety Code for Mechanical Refrigeration.

ASHRAE Standard 34-1992, Number Designation and Safety Classification of Refrigerants.

ASME B31.1, Power Piping.

Boylan, B.R., The Lighting Primer, Iowa State University Press, 1st ed, 1987.

Briley, G.C., Hot Gas Defrost Systems for Large Evaporators in Ammonia Liquid Overfeed Systems, IIAR 14th Annual Meeting, Miami, FL, March 1992.

Briley, G.C., Increasing Operating Efficiency, p. 73, ASHRAE Journal, May 2003.

Briley, G.C., Energy Conservation in Industrial Refrigeration Systems, pp. 46-47, ASHRAE Journal, June 2003.

Briley, G.C., Efficiency for R-717 and R-22 Systems, p. 87, ASHRAE Journal, July 2003.

Briley, G.C., Efficiency for R-717 and R-22 Systems – Part 2, p. 53, ASHRAE Journal, August 2003.

Briley, G.C., Efficiency for R-717 and R-22 Systems – Part 3, p. 58, ASHRAE Journal, September 2003.

Briley, G.C., Efficiency for R-717 and R-22 Systems – Part 4, p. 60, ASHRAE Journal, October 2003.

Briley, G.C., Efficiency for R-717 and R-22 Systems – Part 5, p. 58, ASHRAE Journal, November 2003.

Caffall, C., Learning from Experiences with Energy Management in Industry, CADDET, Sittard, Netherlands, 1995.

Capehart, T., Kennedy, Guide to Energy Management, Fairmont Press, Lilburn, GA, 2000.

Chen, K., Energy Effective Industrial Illumination Systems, The Fairmont Press, 1994.

Corinchock, J.A., Technician's Guide to Refrigeration Systems, McGraw-Hill 1997.

Dinçer, I., Refrigeration Systems and Applications, John Willey & Sons, 2003.

Fetters, J.L., The Handbook of Lighting Surveys and Audits, CRC Press, 1997.

Galitsky, C., Worrell, E. and Ruth, M., Energy Efficiency Improvement and Cost Saving Opportunities for the Corn Wet Milling Industry, EPA, 2003.

Grandison, A.S. and Lewis, M.J. eds., Separation Processes In the Food and Biotechnology Industries, Woodhead Publishing Limited, Cambridge England, 1996.

Incropera, F.P. and Dewitt, D.P., Fundamentals of Heat and Mass Transfer, John Willey & Sons, 5th ed., 2002.

Lindsey, J.L., FIES, Applied Illumination Engineering, Prentice Hall, 1991.

Lithonia Lighting, Industrial Lighting Guide, Quebec, 2000. Learning from Experiences with Industrial Drying Technologies, CADDET Energy Efficiency Analysis Series No. 12, Page 56, CADDET, Sittard, Netherlands, 1994.

Martin, N., Worrell, E., Ruth, M., Price, L., Elliott, R.N., Shipley, A.M. and Thorne, J., Emerging Energy-Efficient Industrial Technologies, LBNL and ACEEE, 2000.

McCoy, G.A. and Douglass, J.G., Energy Management for Motor-Driven Systems, U.S. Department of Energy, Motor Challenge Program, rev. 1, 1997.

McQuiston, F.C., Parker, J.D., and Spitler, J.D., Heating, Ventilating, and Air Conditioning: Analysis and Design, Willey & Sons, 5th ed., 2000.

Moran, M.J. and Shapiro, H.N., Fundamentals of Engineering Thermodynamics, John Willey & Sons, 4th ed., 1999.

Mull, T.E., Practical Guide to Energy Management for Facilities Engineers and Managers, ASME, NY, 2001.

Okos, M., Rao, N., Drecher, S., Rode, M. and Kozac, J., Energy Usage in the Food Industry, ACEEE, 1998.

O’Callaghan, P.W., Energy Management, McGraw-Hill, 1993.

Perry, R.H., Green, D.W., and Maloney, J.O. eds., Perry’s Chemical Engineers’ Handbook, Seventh Edition, McGraw Hill, 1997.

Phillips Lighting Company, Philips Lighting Handbook, 1984.

Rollins, J.P. ed., Compressed Air and Gas Handbook, Prentice-Hall, Inc., 5th ed, 1989.

Singh, R.P. and Heldman, D.R., Introduction to Food Engineering, Academic Press, 3rd ed., 2001.

Stoecker, W.F., Industrial Refrigeration Handbook, 1998.

Talbott, E.M., Compressed Air Systems: A Guidebook on Energy and Cost Savings, Fairmont Press, 2nd ed, 1993.

Thumann, A., Handbook of Energy Audits, Fifth Edition, The Fairmont Press, Inc., 2001.

U.S. Environmental Protection Agency, Green Lights Program: Lighting Upgrade Manual, 4th ed, Feb. 1993.

Wulfinghoff, D.R., Energy Efficiency Manual, Energy Institute, MD, 1999.

The U.S. Department of Energy maintains an extensive listing of publications and articles that provide information on best practices and standards. These publications can be found in a publications library site (www.oit.doe.gov/bestpractices/library.shtml).

ON-LINE TOOLS

Alliance to Save Energy: www.ase.org

Bonneville Power Administration: www.bpa.gov

The Carbon Trust: www.thecarbontrust.co.uk
Publications: www.thecarbontrust.co.uk/energy/pages/publication_search.asp

Compressed Air Challenge: www.compressedairchallenge.org

Earle, R.L., Unit Operations in Food Processing:
www.nzifst.org.nz/unitoperations/index.htm

Energy Information Bridge: www.osti.gov/bridge

Energy Manager Training: www.energymanagertraining.com/new_index.php

Energy Matters: www.oit.doe.gov/bestpractices/energymatters/energy_matters.shtml

Energy Services, Energy Solutions Database: www.energyexperts.org/energy_solutions

Energy Star for Manufacturers: www.energystar.gov/index.cfm?c=manuf_res.pt_manuf

Food Engineering: The Magazine for Manufacturing Management:
www.foodengineeringmag.com

Gartner Refrigeration and Manufacturing: www.gartner-refrig.com
Tips and Tools: www.gartner-refrig.com/resources/tips.asp

The Industrial Refrigeration Consortium: www.irc.wisc.edu.
Downloads: www.irc.wisc.edu/software/downloads.php
Publications: http://www.irc.wisc.edu/publications/

Ingersoll Rand, (2001), Air Solutions Group: Compressed Air Systems Energy Reduction Basics: www.air.ingersoll-rand.com/NEW/pedwards.htm

Lawrence Berkeley National Laboratory, The Energy Analysis Department:
http://eetd.lbl.gov/EA.html

Oak Ridge National Laboratory (ORNL) – Buildings Technology Center:
www.ornl.gov/sci/btc/apps
Building Envelopes Program: www.ornl.gov/sci/roofs+walls/
Insulation Fact Sheet: www.ornl.gov/sci/roofs+walls/insulation/ins_01.html
ZIP-Code Insulation Program: www.ornl.gov/~roofs/Zip/ZipHome.html

Online Chemical Engineering Information, Pinch Technology: Basics for Beginner:
www.cheresources.com/pinchtech1.shtml

Singh, Paul, Teaching Resources: Animation:
www.rpaulsingh.com/animated%20figures/animationlist.htm

Spirax Sarco Learning Center:
www.spiraxsarco.com/learn/default.asp?redirect=html/3_13_01.htm

Steaming Ahead: www.steamingahead.org

U.S. Department of Energy – Energy Efficiency and Renewable Energy:
    www.eere.energy.gov
  Building Technologies Program: www.eere.energy.gov/buildings
    Information Resources: www.eere.energy.gov/buildings/info/publications.html
  Energy Savers: www.eere.energy.gov/consumerinfo
  Energy Information Bridge: www.osti.gov/bridge
  Industrial Technologies Program: www.eere.energy.gov/industry
    BestPractices: www.oit.doe.gov/bestpractices
      Compressed Air: www.oit.doe.gov/bestpractices/compressed_air
      Energy Matters:
      www.oit.doe.gov/bestpractices/energymatters/energy_matters.shtml
      Fact Sheets: www.oit.doe.gov/factsheets/fact_other.shtml
      Motors: www.oit.doe.gov/bestpractices/motors
      Plant-Wide Assessments: www.oit.doe.gov/bestpractices/assessments.shtml
      Process Heating: www.oit.doe.gov/bestpractices/process_heat
      Tools and Publications: www.oit.doe.gov/bestpractices/pubs.shtml
        EERE Information Center: 1-877-EERE-INF or eereic@ee.doe.gov
        Publications Library: www.oit.doe.gov/bestpractices/library.shtml

- Technical Publications
- Case Studies
- Plant-Wide Assessment Summaries
- Energy Matters
- Training Materials
- Library Links

Software Tools: www.oit.doe.gov/bestpractices/software_tools.shtml

- AIRMaster+
- Fan System Assessment Tool (FAST)
- MotorMaster+
- MotorMaster+ International
- NOx and Energy Assessment Tool (NxEAT)
- Process Heating Assessment and Survey Tool (PHAST)
- Pumping System Assessment Tool (PSAT)
- Steam System Tool Suite
  - Steam System Scoping Tool (SSST)
  - Steam System Assessment Tool (SSAT)
  - 3EPlus
- Decision Tools for Industry
- ASDMaster: Adjustable Speed Drive Evaluation Methodology and Application

Steam: www.oit.doe.gov/bestpractices/steam

Simply Insulate: www.simplyinsulate.com

ORGANIZATIONS

Alliance to Save Energy: www.ase.org

American Council for an Energy Efficient Economy: www.aceee.org

American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE): www.ashrae.org

Association of Energy Engineers: www.aeecenter.org

Boiler Efficiency Institute: www.boilerinstitute.com

British Compressed Air Society: www.britishcompressedairsociety.co.uk

The Carbon Trust: www.thecarbontrust.co.uk/energy

Centre for Analysis and Dissemination of Demonstrated Energy Technologies (CADDET): www.caddet.org

Council of Industrial Boiler Owners (CIBO): www.cibo.org.

Energy User News: www.energyusernews.com

Food and Drink Federation, Voice of the UK Food and Drink Manufacturing Industry: www.fdf.org.uk/home.aspx

Gas Research Institute: www.gri.org

The Industrial Refrigeration Consortium: www.irc.wisc.edu

International Energy Agency: www.iea.org

International Institute of Ammonia Refrigeration: www.iiar.org

Iowa Energy Center: www.energy.iastate.edu

Iowa State University Industrial Assessment Center (IAC): (515) 294-3080 or www.me.iastate.edu/iac

Lawrence Berkeley National Laboratory, The Energy Analysis Department, National: http://eetd.lbl.gov/EA.html

National Electrical Manufacturers Association: www.nema.org

North American Insulation Manufacturers Association (NAIMA): www.naima.org

Sustainable by Design: www.susdesign.com

Technical Information Services: www.ntis.gov

United Kingdom Energy Efficiency: www.etsu.com

Coordinated by:

The **Center for Industrial Research and Service (CIRAS)** works with Iowa State University Extension and the College of Engineering to enhance the performance of Iowa industry. This is accomplished by providing research, education and technical assistance in the areas of engineering, management, procurement, productivity and quality.

Center for Industrial Research and Service (CIRAS)
2272 Howe Hall, Suite 2620
Ames, IA 50011

For questions regarding manufacturing and industry contact:
CIRAS
(515) 294-3420
www.ciras.iastate.edu

Sponsored by:

The **Iowa Energy Center** is dedicated to improving Iowa's energy efficiency and use of renewable energy through research, demonstration, and education. The Energy Center develops in-house energy-related research and education programs and sponsors energy projects developed by other groups. The Energy Center also administers the Alternate Energy Revolving Loan Program.

2521 Elwood Drive, Suite 124
Ames, Iowa 50010
www.energy.iastate.edu