LBNL-57260-Revision

Energy Efficiency Improvement and Cost Saving Opportunities for the Pharmaceutical Industry

An ENERGY STAR® Guide for Energy and Plant Managers

Christina Galitsky, Sheng-chieh Chang, Ernst Worrell, and Eric Masanet

Energy Analysis Department
Environmental Energy Technologies Division
Ernest Orlando Lawrence Berkeley National Laboratory
University of California
Berkeley, California 94720

March 2008

This work was funded by U.S. Environmental Protection Agency's Climate Protection Partnerships Division as part of ENERGY STAR. ENERGY STAR is a government-backed program that helps businesses protect the environment through superior energy efficiency. The work was supported by the U.S. Environmental Protection Agency through the U.S. Department of Energy Contract No. DE-AC02-05CH11231.

Energy Efficiency Improvement and Cost Saving Opportunities for the Pharmaceutical Industry

An ENERGY STAR® Guide for Energy and Plant Managers

Christina Galitsky, Sheng-chieh Chang, Ernst Worrell, and Eric Masanet

Energy Analysis Department
Environmental Energy Technologies Division
Ernest Orlando Lawrence Berkeley National Laboratory
University of California
Berkeley, California 94720

March 2008

ABSTRACT

The U.S. pharmaceutical industry consumes almost $1 billion in energy annually. Energy efficiency improvement is an important way to reduce these costs and to increase predictable earnings, especially in times of high energy price volatility. There are a variety of opportunities available at individual plants in the U.S. pharmaceutical industry to reduce energy consumption in a cost-effective manner. This Energy Guide discusses energy efficiency practices and energy efficient technologies that can be implemented at the component, process, system, and organizational levels. A discussion of the trends, structure, and energy consumption characteristics of the U.S. pharmaceutical industry is provided along with a description of the major process steps in the pharmaceutical manufacturing process. Expected savings in energy and energy-related costs are given for many energy efficiency measures, based on case study data from real-world applications in pharmaceutical and related facilities worldwide. Typical measure payback periods and references to further information in the technical literature are also provided, when available. The information in this Energy Guide is intended to help energy and plant managers reduce energy consumption in a cost-effective manner while meeting regulatory requirements and maintaining the quality of products manufactured. At individual plants, further research on the economics of the measures—as well as their applicability to different production practices—is needed to assess potential implementation of selected technologies.

Table of Contents

1. Introduction

As U.S. manufacturers face an increasingly competitive environment, they seek out opportunities to reduce production costs without negatively affecting the yield or the quality of their finished products. The volatility of energy prices in today's marketplace can also negatively affect predictable earnings. This is a concern particularly for publicly-traded companies in the pharmaceutical industry. The challenge of maintaining high product quality while simultaneously reducing production costs can often be met through investments in energy efficient technologies and energy efficiency practices. Energy efficient technologies can often offer additional benefits, such as quality improvement, increased production, and increased process efficiency, which can lead to further productivity gains. Energy efficiency is also an important component of a company's environmental strategy, as energy efficiency improvements can often lead to reductions in pollutant emissions. A strong energy management program can also provide a solid foundation for corporate greenhouse gas management programs. In short, investment in energy efficiency is a sound business strategy in today's manufacturing environment.

To help industry improve its competitiveness through increased energy efficiency and reduced environmental impact, the federal government offers several voluntary programs. The ENERGY STAR® program is a voluntary program operated by the U.S. Environmental Protection Agency (EPA) in coordination with the U.S. Department of Energy (DOE) that stresses the need for strong and strategic corporate energy management programs. ENERGY STAR also provides a host of energy management tools and strategies to support the successful implementation of corporate energy management programs. This Energy Guide reports on research conducted to support the U.S. EPA's ENERGY STAR Pharmaceutical Focus, which works with the U.S. pharmaceutical industry to identify information and resources for energy efficiency improvement. For further information on ENERGY STAR and its available tools for facilitating corporate energy management practices, visit http://www.energystar.gov/.

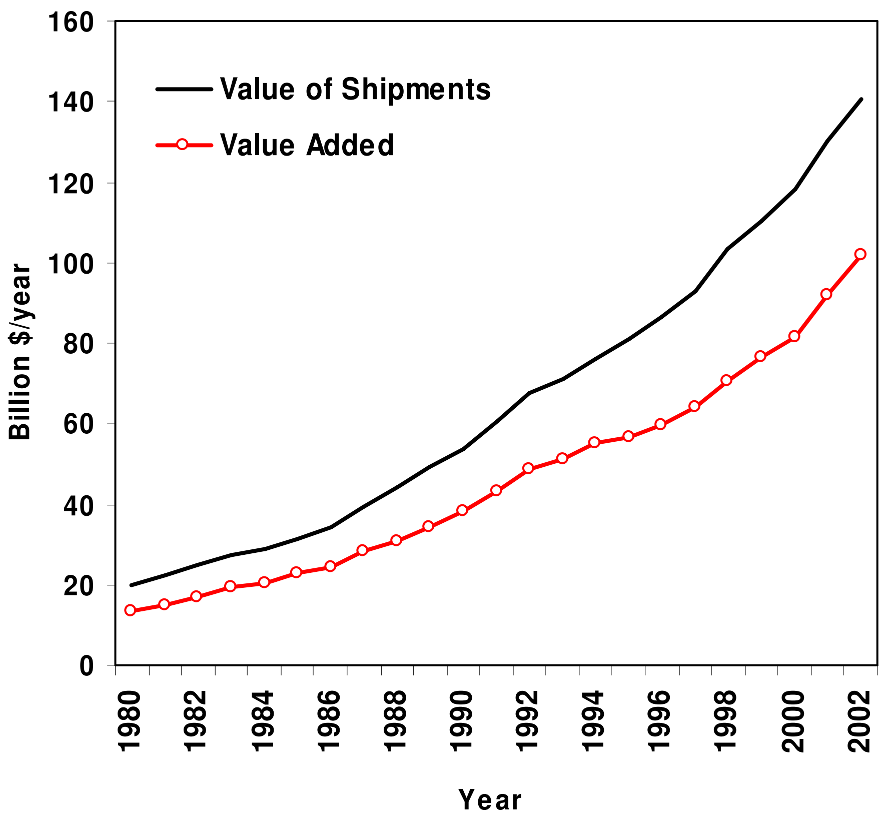
This Energy Guide assesses energy efficiency opportunities for the U.S. pharmaceutical industry. The manufacture of pharmaceuticals and medicines is a key industry in the United States. In 2002, the U.S. pharmaceutical industry generated over $140 billion in output, up from $108 billion in output in 1999 (U.S. Census 2001, 2005a). The industry employed nearly 250,000 people directly in 2002 (U.S. Census 2005a). Pharmaceutical production facilities can be found throughout the United States; however, production is mainly concentrated in a few states. Although energy costs typically represent a small percentage of total production costs in the pharmaceutical industry, the cost of energy is still significant. In 2002, the total cost of purchased fuels and electricity in the U.S. pharmaceutical industry was over $920 million (U.S. Census 2005a). Furthermore, energy costs are growing rapidly due to increased costs for natural gas and electricity in the United States, making energy management an important focus area for improvement of operations and productivity.

This Energy Guide first describes the trends, structure, and production characteristics of the U.S. pharmaceutical industry. Next, a description of the main production processes and a discussion of energy use in the pharmaceutical industry, including the main end uses of energy, are provided. Due to the wide variety of products and production methods in the U.S. pharmaceutical industry, it is impossible to describe all energy end uses. Therefore, this Energy Guide focuses on the most important end uses of energy in typical U.S. pharmaceutical plants. Finally, the remainder of this Energy Guide discusses opportunities for energy efficiency improvement in U.S. pharmaceutical plants, focusing on energy efficient measures and technologies that have successfully been demonstrated in individual plants in the United States or abroad. Although new energy efficient technologies are developed continuously (see for example Martin et al. 2000), this Energy Guide focuses on those technologies and practices that are both proven and currently commercially available.

2. The Pharmaceutical Industry

The U.S. pharmaceutical industry encompasses a wide array of products. This Energy Guide focuses on the U.S. "pharmaceutical and medicine manufacturing" industry, which is designated by the North American Industry Classification System (NAICS) code 3254.[1] The U.S. pharmaceutical and medicine manufacturing industry includes medicinal and botanical manufacturing (NAICS 325411), pharmaceutical preparation manufacturing (NAICS 325412), in-vitro diagnostic substance manufacturing (NAICS 325413), and biological product (except diagnostic) manufacturing (NAICS 325414). Pharmaceutical preparation manufacturing has historically represented the vast share of total U.S. pharmaceutical and medicine production (approximately 75%). Although other industry segments have shown strong growth over the past decade, such as biological product manufacturing, these segments still produce less than 25% of the U.S. pharmaceutical industry's total value added (U.S. Census 2005a).

Figure 1. Value of shipments and value added of the U.S. pharmaceutical industry, 1980-2002.



Sources: National Bureau of Economic Research (2000); U.S. Census (2003, 2005a).

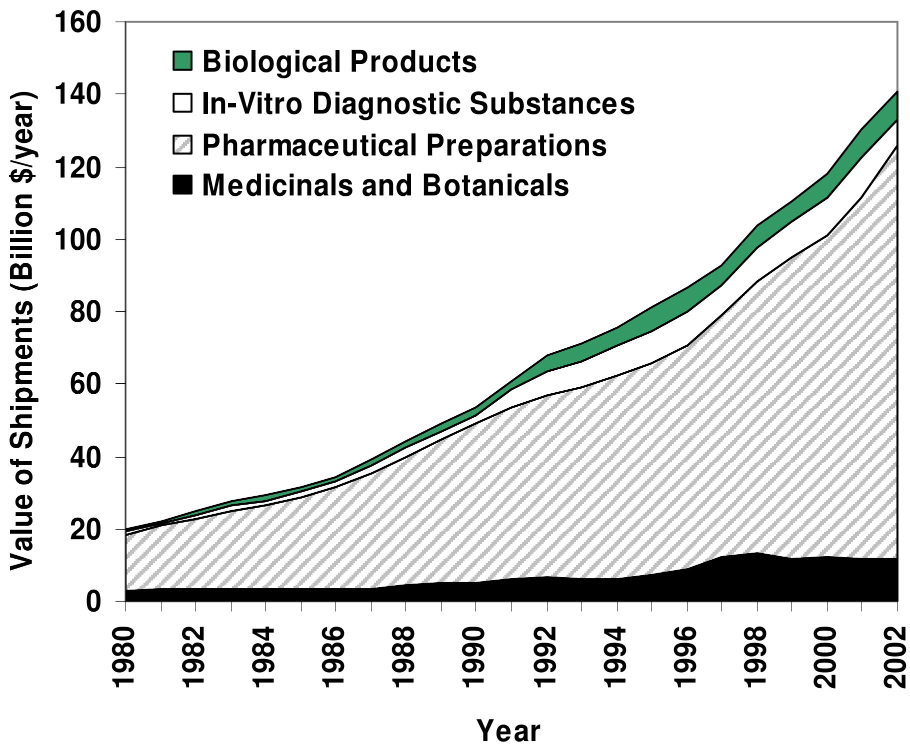
[1] Formerly Standard Industrial Classification (SIC) code 283.

Total production value of the U.S. pharmaceutical industry has increased rapidly over the past 20 years, as shown in Figure 1. Figure 1 plots value added and value of shipments for the U.S. pharmaceutical industry from 1980-2002. It can be seen in Figure 1 that the value added generated by this industry has grown almost parallel to the output growth. Value added as a function of value of shipments in the U.S. pharmaceutical industry has been nearly constant at around 70% for the past two decades. In 2002, the output of the U.S. pharmaceutical industry ($141 billion) was more than a quarter of the output of the U.S. chemical industry ($460 billion) as a whole (U.S. Census 2005a).

The global market for pharmaceutical products in 2002 was estimated at just over $400 billion (IMS Health 2003). Of this, the United States was the largest market by far, accounting for nearly half of global pharmaceutical sales. The U.S. market is also the fastest growing pharmaceutical market in the world, with an average annual growth rate of 14% since 1999 (IMS Health 2005).

Figure 2 plots historical value of shipments data for the four major segments of the U.S. pharmaceutical industry, clearly demonstrating the importance of pharmaceutical preparations manufacturing despite strong growth in the other segments. Figure 2 also demonstrates the strong growth of the U.S. pharmaceutical industry overall in the past two decades.

Figure 2. Value of shipments of the four major segments of the U.S. pharmaceutical industry.



Sources: National Bureau of Economic Research (2000); U.S. Census (2003, 2005a).

Today, the U.S. pharmaceutical industry is dominated by a number of large pharmaceutical manufacturers, which also operate globally. In 2002, the top 10 companies accounted for nearly half of all global pharmaceutical sales (Sellers 2003). Often, a few drugs may be a major source of income to the industry. For example, in 2002, global sales of the top five drugs together were valued at $28 billion (IMS Health 2003).

Major pharmaceutical companies in the United States are summarized in Table 1. While pharmaceutical production facilities can be found throughout the United States, most of the companies are headquartered in the northeastern states. The U.S. pharmaceutical industry employed nearly 250,000 people directly in 2002 (U.S. Census 2005a). United States pharmaceutical production is mainly located in Pennsylvania, North Carolina, California, New Jersey, and New York (see Table 2). There is also considerable production of pharmaceuticals occurring in the U.S. Commonwealth of Puerto Rico. According to the Pharmaceutical Industry Association of Puerto Rico, in 2003 the Puerto Rican pharmaceutical industry provided over 30,000 direct jobs and exported nearly $37 billion worth of pharmaceuticals from the island (PIAPR 2005).

Table 1. Major pharmaceutical companies[2] in the United States (in alphabetical order).

Company	**U.S. Headquarters**	**2002 Sales** (Billion $)
Abbott Laboratories	Abbot Park, Illinois	9.27
Amgen	Thousand Oaks, California	4.99
AstraZeneca	Wilmington, Delaware	17.84
Aventis	Bridgewater, New Jersey	17.25
Baxter Healthcare	Deerfield, Illinois	3.10
Bayer	West Haven, Connecticut	5.12
Boehringer Ingelheim	Ridgefield, Connecticut	7.92
Bristol-Myers Squibb	New York, NY	14.70
GlaxoSmithKline	Research Triangle Park, North Carolina	28.20
Hoffman-La Roche	Nutley, New Jersey	10.81
Johnson & Johnson	New Brunswick, New Jersey	17.20
Eli Lilly	Indianapolis, Indiana	11.07
Merck & Co.	Whitehouse Station, New Jersey	21.63
Novartis	East Hanover, New Jersey	15.36
Pharmacia[3]	See note	12.03
Pfizer	New York, New York	28.28
Schering-Plough	Kenilworth, New Jersey	8.70
Wyeth	Madison, New Jersey	11.70

[2] Sales in Table 1 include all sales by each company categorized as "Pharmaceutical Companies" by the U.S. Census, and may include sales of products other than ethical drugs, such as healthcare or other products. Sales data are based on 2002 global sales (Sellers 2003).

[3] Pfizer acquired Pharmacia in 2003, making Pfizer the largest pharmaceutical company in the world.

Table 2. Geographic distribution of the pharmaceutical industry by U.S. state in 2002.[4] The top 10 states are given for employment and total value of shipments. States are presented in alphabetical order.

State	**2002 Value of Shipments**		**2002 Employees**	
	Billion $	**Share U.S. (%)**	**Number**	**Share U.S. (%)**
California	10.60	7.5%	59,253	23.8%
Connecticut	3.09	2.2%	7,819	3.1%
Illinois	8.34	5.9%	22,373	9.0%
Indiana	7.52	5.3%	8,956	3.6%
Massachusetts	3.63	2.6%	9,118	3.7%
Michigan	3.78	2.7%	6,269	2.5%
New Jersey	13.10	9.3%	31,164	12.5%
New York	17.09	12.1%	22,264	8.9%
North Carolina	15.53	11.0%	13,413	5.4%
Pennsylvania	19.77	14.0%	11,770	4.7%
U.S.	**141.15**		**249,384**	

Sources: U.S. Census (2005a-2005e).

The pharmaceutical industry is also research intensive. The major pharmaceutical companies listed in Table 1 spent approximately $42 billion in 2002 on research and development (R&D), or, on average, 17% of global sales (Sellers 2003). The pharmaceutical industry is therefore one of the most R&D intensive industries, both in the United States and in the world. Pharmaceutical production and research are also closely integrated; in fact, in many locations production facilities can be found next to R&D laboratories on the same site.

[4] 2002 U.S. Census data for pharmaceutical manufacturing in Puerto Rico were not available at the time of this writing. However, 1997 U.S. Census data for Puerto Rico show direct employment of 24,892 and a total value of shipments of $23.12 billion for the Puerto Rican pharmaceutical industry (U.S. Census 2000).

3. Process Description

There are three overall stages in the production of bulk pharmaceutical products: (1) R&D, (2) conversion of natural substances to bulk pharmaceuticals, and (3) formulation of final products. Figure 3 provides an overview of the main process steps in the manufacture of pharmaceuticals. Each of these stages is described in more detail below.[5]

Figure 3. Main process steps in the manufacture of pharmaceuticals.

Research & Development	Four stages: 1. Pre-clinical R&D: determine if substance is active and safe (6 years) 2. Clinical R&D: human testing (6 years) 3. Review of new drug application (1-2 years) 4. Post marketing surveillance
Conversion of natural substances to bulk pharmaceutical substances	Types of conversion: • Chemical Synthesis • Fermentation • Extraction
Formulation of final products	Conversion of substances at a much larger scale

3.1 Research & Development

Because it is highly regulated, R&D is the longest stage in pharmaceutical product manufacturing. After identifying several thousands of compounds at the beginning stages of R&D, only one will be introduced as a new pharmaceutical drug. Many resources go into this stage of development.

The four basic stages of R&D are listed above in Figure 3: (1) pre-clinical R&D, (2) clinical R&D, (3) review of new drug application, and (4) post marketing surveillance. In the pre-clinical R&D stage, compounds are tested on animals to determine biological activity and safety. This testing takes about six years on average to complete. After pre-clinical trials, an Investigational New Drug Application is filed with the U.S. Food and Drug Administration (FDA), the purpose of which is to provide data showing that it is reasonable to begin tests of a new drug on humans.

The next stage, clinical R&D, is typically conducted in three phases, each with progressively more human participants. The first phase of clinical R&D determines the safety of a new drug, the second phase determines a new drug's effectiveness, and the third phase provides

[5] Further details on pharmaceutical manufacturing processes can be found in the U.S. EPA's *Profile of the Pharmaceutical Manufacturing Industry* (U.S. EPA 1997).

further confirmation of safety and effectiveness along with determination of any adverse reactions. The clinical R&D stage altogether takes, on average, about six years to complete.

At the next stage, the pharmaceutical company files a New Drug Application (NDA) with the U.S. FDA. As of 1996, approval times for NDAs were approximately 15 months (U.S. EPA 1997).

Finally, after a new drug has been approved for marketing, the U.S. FDA monitors the ongoing safety of marketed drugs via post marketing surveillance. Also, the pharmaceutical manufacturer will evaluate various ways of formulating the drug on a larger scale for optimum delivery.

3.2 Conversion to Bulk Pharmaceutical Substances

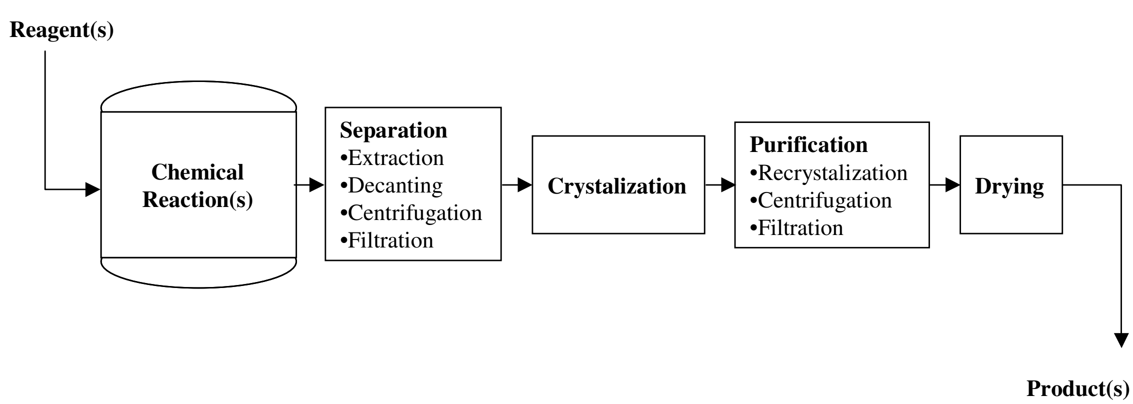
Bulk pharmaceutical substances are produced via chemical synthesis, extraction, fermentation, or a combination of these processes (U.S. EPA 1997). Antihistamines, cardiovascular agents, central nervous system stimulants, and hormones are produced by chemical synthesis. Enzymes and digestive aids, allergy relief medicines, hematological agents, insulin, anti-cancer drugs, and vaccines are extracted from naturally-occurring substances. Most steroids, antibiotics, and some food additives, like vitamins, are produced by fermentation. Antibiotics, antineoplastic agents, central nervous system depressants, and vitamins are typically produced by more than one of these three processes.

Chemical synthesis, extraction, and fermentation are discussed separately below. For further information on these processes, see the U.S. EPA's *Profile of the Pharmaceutical Manufacturing Industry* (U.S. EPA 1997).

Chemical Synthesis

Figure 4 shows a simplified diagram of the chemical synthesis process for pharmaceuticals. There are five primary stages in chemical synthesis: (i) reaction, (ii) separation, (iii) crystallization, (iv) purification, and (v) drying. Each of these five stages is described below.

Figure 4. Simplified chemical synthesis diagram (adapted from U.S. EPA 1997)



(i) Reaction. In the reaction process, raw materials are fed into a reactor vessel, where reactions such as alkylations, hydrogenations, or brominations are performed. The most common type of reactor vessel is the kettle-type reactor. These reactors, which are generally made of stainless steel or glass-lined carbon steel, range from 50 to several thousand gallons in capacity. The reactors may be heated or cooled, and reactions may be performed at atmospheric pressure, at elevated pressure, or in a vacuum. Generally, both reaction temperature and pressure are monitored and controlled. Nitrogen may be required for purging the reactor, and some intermediates may be recycled back into the feed. Some reactions are aided via mixing action provided by an agitator. A condenser system may be required to control vent losses. Reactors are often attached to pollution control devices to remove volatile organics or other compounds from vented gases.

(ii) Separation. The main types of separation processes are extraction, decanting, centrifugation, filtration, and crystallization. Crystallization is used by many plants and is discussed separately below.

The extraction process is used to separate liquid mixtures. Extraction takes advantage of the differences in the solubility of mixture components. A solvent that preferentially combines with only one of the mixture components is added to the mixture. Two streams result from this process: the extract, which is the solvent-rich solution containing the desired mixture component, and the raffinate, which is the residual feed solution containing the non-desired mixture component(s).

Decanting is a simple process that removes liquids from insoluble solids that have settled to the bottom of a reactor or settling vessel. The liquid is either pumped out of the vessel or poured from the vessel, leaving only the solid and a small amount of liquid in the vessel.

Centrifugation is a process that removes solids from a liquid stream using the principle of centrifugal force. A liquid-solid mixture is added to a rotating vessel—or centrifuge—and an outward force pushes the liquid through a filter that retains the solid phase. The solids are manually scraped off the sides of the vessel or with an internal scraper. To avoid air infiltration, centrifuges are usually operated under a nitrogen atmosphere and kept sealed during operation.

Filtration separates fluid/solid mixtures by flowing fluid through a porous media, which filters out the solid particulates. Batch filtration systems widely used by the pharmaceutical industry include plate and frame filters, cartridge filters, nutsche filters, and filter/dryer combinations.

(iii) Crystallization. Crystallization is a widely used separation technique that is often used alone or in combination with one or more of the separation processes described above. Crystallization refers to the formation of solid crystals from a supersaturated solution. The most common methods of super saturation in practice are cooling, solvent evaporation, and chemical reaction. The solute that has crystallized is subsequently removed from the solution by centrifugation or filtration.

(iv) Purification. Purification follows separation, and typically uses the separation methods described above. Several steps are often required to achieve the desired purity level. Recrystallization is a common technique employed in purification. Another common approach is washing with additional solvents, followed by filtration.

(v) Drying. The final step in chemical synthesis is drying the product (or intermediates). Drying is done by evaporating solvents from solids. Solvents are then condensed for reuse or disposal. The pharmaceutical industry uses several different types of dryers, including tray dryers, rotary dryers, drum or tumble dryers, or pressure filter dryers. Prior to 1980, the most common type of dryer used by the pharmaceutical industry was the vacuum tray dryer. Today, however, the most common dryers are tumble dryers or combination filter/dryers. In the combination filter/dryer, an input slurry is first filtered into a cake, after which a hot gaseous medium is blown up through the filter cake until the desired level of dryness is achieved. Tumble dryers typically range in capacity from 20 to 100 gallons. In tumble dryers, a rotating conical shell enhances solvent evaporation while blending the contents of the dryer. Tumble dryers utilize hot air circulation or a vacuum combined with conduction from heated surfaces.

Product Extraction

Active ingredients that are extracted from natural sources are often present in very low concentrations. The volume of finished product is often an order of magnitude smaller than the raw materials, making product extraction an inherently expensive process.

Precipitation, purification, and solvent extraction methods are used to recover active ingredients in the extraction process. Solubility can be changed by pH adjustment, by salt formation, or by the addition of an anti-solvent to isolate desired components in precipitation. Solvents can be used to remove active ingredients from solid components like plant or animal tissues, or to remove fats and oils from the desired product. Ammonia is often used in natural extraction as a means of controlling pH.

Fermentation

In fermentation, microorganisms are typically introduced into a liquid to produce pharmaceuticals as by-products of normal microorganism metabolism. The fermentation process is typically controlled at a particular temperature and pH level under a set of aerobic or anaerobic conditions that are conducive to rapid microorganism growth. The process involves three main steps: (i) seed preparation, (ii) fermentation, and (iii) product recovery.

(i) Seed preparation. The fermentation process begins with seed preparation, where inoculum (a medium containing microorganisms) is produced in small batches within seed tanks. Seed tanks are typically 1-10% of the size of production fermentation tanks (U.S. EPA 1997).

(ii) Fermentation. After creating the inoculum at the seed preparation stage, the inoculum is introduced into production fermentors. In general, the fermentor is agitated, aerated, and controlled for pH, temperature, and dissolved oxygen levels to optimize the fermentation process. The fermentation process lasts from hours to weeks, depending on the product and process.

(iii) Product Recovery. When fermentation is complete, the desired pharmaceutical by-products need to be recovered from the fermented liquid mixture. Solvent extraction, direct precipitation, and ion exchange may be used to recover the product. Additionally, if the product is contained within the microorganism used in fermentation, heating or ultrasound may be required to break the microorganism's cell wall. In solvent extraction, organic solvents are employed to separate the product from the aqueous solution. The product can then be removed from the solvent by crystallization. In direct precipitation, products are precipitated out of solution using precipitating agents like metal salts. In ion exchange, the product adsorbs onto an ion exchange resin and is later recovered from the resin using solvents, acids, or bases.

3.3 Formulation of Final Products

The final stage of pharmaceutical manufacturing is the conversion of manufactured bulk substances into final, usable forms. Common forms of pharmaceutical products include tablets, capsules, liquids, creams and ointments, aerosols, patches, and injectable dosages. Tablets account for the majority of pharmaceutical solids taken orally in the United States (U.S. EPA 1997).

To prepare a tablet, the active ingredient is combined with a filler (such as sugar or starch), a binder (such as corn syrup or starch), and sometimes a lubricant (such as magnesium sterate or polyethylene glycol). The filler ensures the proper concentration of the active ingredient; the purpose of the binder is to bond tablet particles together. The lubricant may facilitate equipment operation during tablet manufacture and can also help to slow the disintegration of active ingredients.

Tablets are produced via the compression of powders. Wet granulation or dry granulation processes may be used. In wet granulation, the active ingredient is powdered and mixed with the filler, wetted and blended with the binder in solution, mixed with lubricants, and finally compressed into tablets. Dry granulation is used when tablet ingredients are sensitive to moisture or drying temperatures. Coatings, if used, are applied to tablets in a rotary drum, into which the coating solution is poured. Once coated, the tablets are dried in the rotary drum; they may also be sent to another drum for polishing.

Capsules are the second most common solid oral pharmaceutical product in the United States after tablets (U.S. EPA 1997). Capsules are first constructed using a mold to form the outer shell of the capsule, which is typically made of gelatin. Temperature controls during the molding process control the viscosity of the gelatin, which in turn determines the thickness of the capsule walls. The capsule's ingredients are then poured (hard capsules) or injected (soft capsules) into the mold.

For liquid pharmaceutical formulations, the active ingredients are weighed and dissolved into a liquid base. The resulting solutions are then mixed in glass-lined or stainless steel vessels and tanks. Preservatives may be added to the solution to prevent mold and bacterial growth. If the liquid is to be used orally or for injection, sterilization is required.

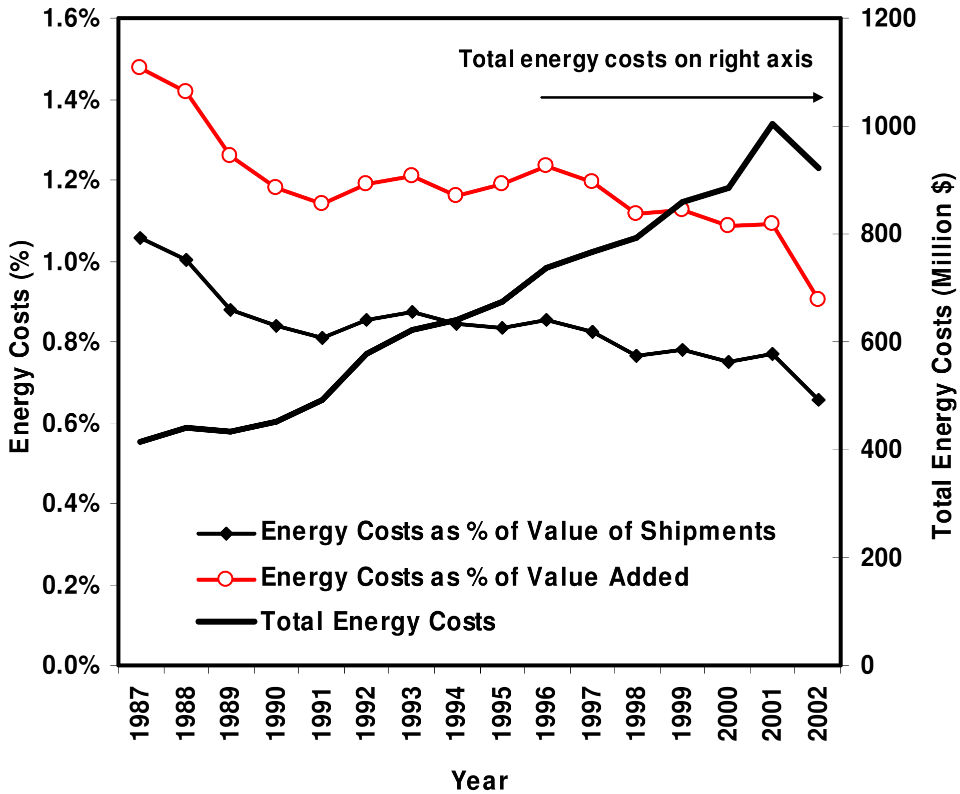
Ointments are made by blending active ingredients with a petroleum derivative or wax base. The mixture is cooled, rolled out, poured into tubes, and packaged.

Creams are semisolid emulsions of oil-in-water or water-in-oil; each phase is heated separately and then mixed together to form the final product.

4. Energy Use in the U.S. Pharmaceutical Industry

The U.S. pharmaceutical industry's energy costs have grown steadily since 1987, and closely follow the industry's increases in value added and value of shipments over the past two decades (see Figure 1). Figure 5 plots the U.S. pharmaceutical industry's energy costs, energy costs as a percentage of value added, and energy costs as a percentage of value of shipments from 1987-2002. Figure 5 shows that total energy costs have increased steadily since 1987, while energy costs as a percentage of production (i.e., value added and value of shipments) have decreased over the same period. The downward trend in energy costs as a percentage of value added and value of shipments can be due to changes in the activities and profitability of the industry, and may not necessarily indicate that the energy consumed per physical unit of product has changed over the same period.

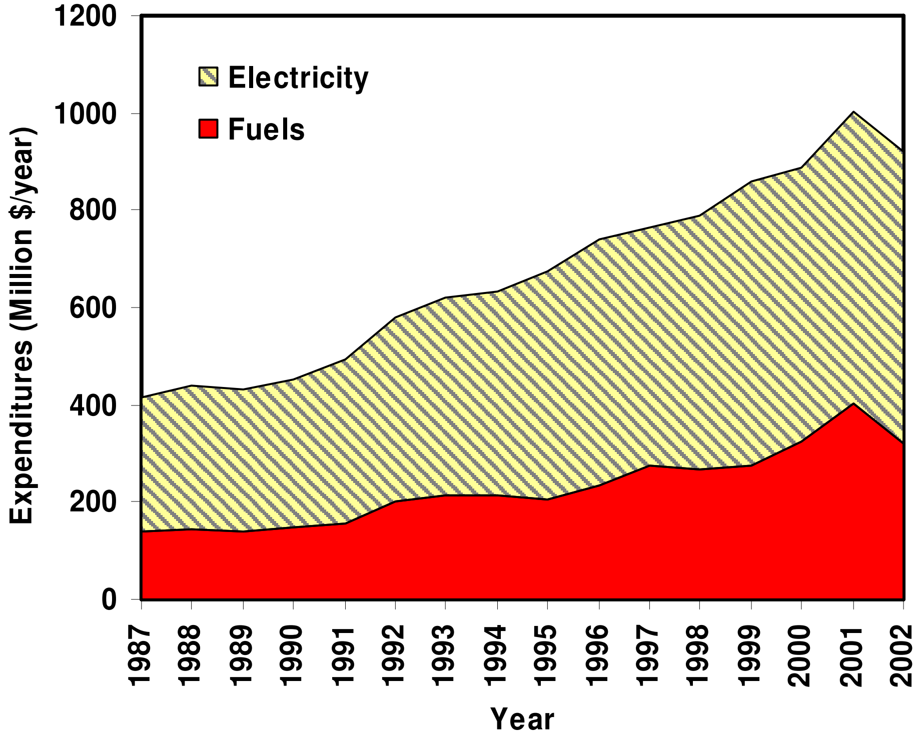
Figure 5. Historical trends in energy costs for the U.S. pharmaceutical industry.



Sources: U.S. Census (1990, 1993, 1995, 1996, 1998, 2003, 2005a).

Figure 6 shows the energy expenditures of the U.S. pharmaceutical industry from 1987-2002, broken down by electricity and fuel expenditures. Expenditures on both electricity and fuels have risen steadily since 1987. However, electricity expenditures have risen at a higher rate than fuel expenditures. The actual electricity use in the U.S. pharmaceutical industry did not increase as rapidly as electricity costs, as shown in Figure 7.

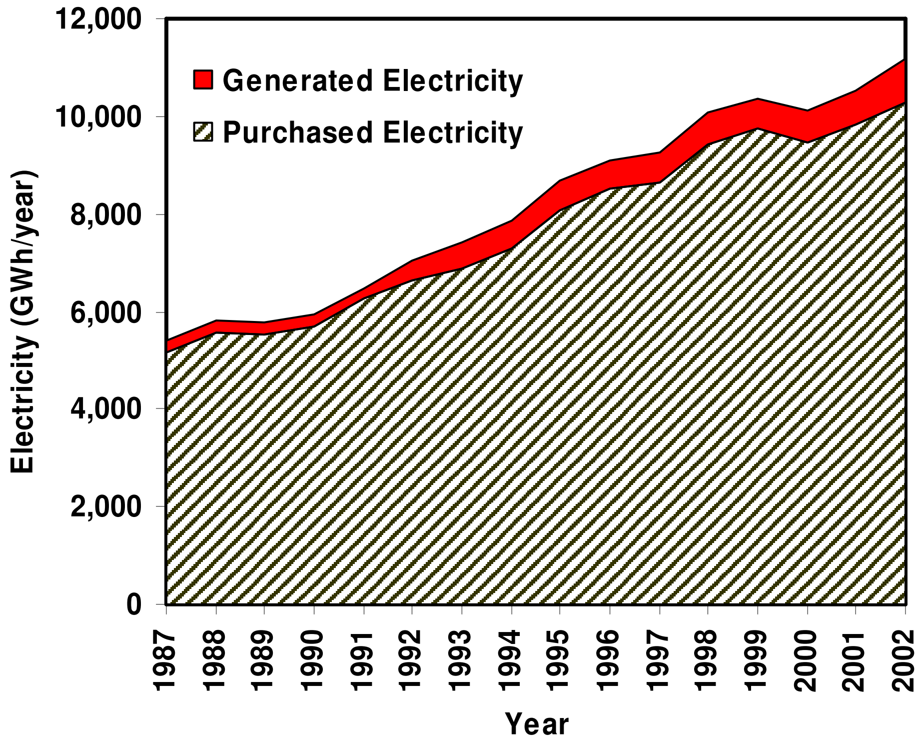
Figure 6. Historical energy expenditures of the U.S. pharmaceutical industry.



Sources: U.S. Census (1990, 1993, 1995, 1996, 1998, 2003, 2005a).

Figure 7 depicts the trend in total electricity consumption in the U.S. pharmaceutical industry from 1987-2002. It can also be seen in Figure 7 that the use of cogeneration is still limited in the U.S. pharmaceutical industry, despite a slight increase since 1987. In 1987, electricity generation accounted for 4.8% of total electricity consumption; by 2002, that percentage had risen to 8.8%.

Figure 7. Historical electricity consumption in the U.S. pharmaceutical industry.



Sources: U.S. Census (1990, 1993, 1995, 1996, 1998, 2003, 2005a).

Energy is used for a wide variety of applications within the U.S. pharmaceutical industry. Chapter 3 discussed the range of different process technologies used in pharmaceutical production; the particular processes employed in a production sequence will vary by product and by plant. Hence, energy use will vary widely from location to location. The key factors affecting a plant's energy consumption include facility type (e.g., R&D or bulk production), the products produced, the plant's location, and the efficiency of the plant's major systems. However, based on the typical steps in the pharmaceutical manufacturing process and the types of energy end uses necessary to support this process, it is possible to develop a rough breakdown of the industry's energy consumption.

Table 3 provides an estimated energy consumption breakdown for the U.S. pharmaceutical industry as a whole, categorized by major activity area (listed in rows) and end use (listed in columns). The estimates in Table 3 do not refer to any particular plant, nor do they attempt to estimate the energy use at a "typical" pharmaceutical plant.[6] In addition, Table 3 shows the main energy uses for each activity area and end use category. The energy distribution in Table 3 may not apply to all facilities nor is it assumed to be exhaustive.

[6] Because of the variability between plants in the pharmaceutical industry today, including some facilities that only contain one activity area listed in Table 3, this Energy Guide does not attempt to define a "typical" pharmaceutical plant.

Heating, ventilation, and air conditioning (HVAC) is typically the most important energy end use in the pharmaceutical industry. Table 3 also shows that R&D and bulk manufacturing are typically the most important energy consuming activities in the pharmaceutical industry.

Table 3. Distribution of energy use in the pharmaceutical industry.

	Overall	Plug loads and processes	Lighting	Heating, ventilation and air conditioning (HVAC)
Total	**100%**	**25%**	**10%**	**65%**
R&D	**30%**	Microscopes Centrifuges Electric mixers Analysis equipment Sterilization processes Incubators Walk in/reach in areas (refrigeration)	Task and overhead lighting	Ventilation for clean rooms and fume hoods Areas requiring 100% make-up air Chilled water Hot water and steam
Offices	**10%**	Office equipment including computers, fax machines, photocopiers, printers Water heating (9%)*	Task, overhead, and outdoor lighting	Space heating (25%)* Cooling (9%)* Ventilation (5%)*
Bulk Manufacturing	**35%**	Centrifuges Sterilization processes Incubators Dryers Separation processes	Task and overhead lighting	Ventilation for clean rooms and fume hoods Areas requiring 100% make-up air Chilled water Hot water and steam
Formulation, Packaging & Filling	**15%**	Mixers Motors	Mostly overhead, some task	Particle control ventilation
Warehouses	**5%**	Forklifts Water heating (5%)*	Mostly overhead lighting	Space heating (41%)* Refrigeration (4%)*
Miscellaneous	**5%**		Overhead	

* Percentages for water heating, space heating, cooling, refrigeration, and ventilation are derived from the U.S. DOE's Commercial Building Energy Consumption Survey (CBECS) for commercial office or warehouse buildings (U.S. DOE 1999). These numbers are only shown as first approximations and in reality will vary from facility to facility.

5. Energy Efficiency Opportunities for the Pharmaceutical Industry

A variety of opportunities exist within U.S. pharmaceutical laboratories, manufacturing facilities, and other buildings to reduce energy consumption while maintaining or enhancing productivity. Table 4 categorizes available energy efficiency opportunities by the six major activity areas listed in Table 3: (1) R&D, (2) bulk manufacturing, (3) formulation, packaging and filling, (4) warehouses, (5) offices, and (6) miscellaneous. For each major activity area, Table 4 also provides references to the sections in this Energy Guide that describe relevant energy efficiency measures. Measure descriptions include case studies for U.S. pharmaceutical plants with specific energy and cost savings data, when such case study data are available. For measures where data are not available for U.S. pharmaceutical plants, this Energy Guide includes case study data from non-U.S. pharmaceutical facilities or case study data from similar industries (for example, chemical manufacturing).

For individual pharmaceutical facilities, the actual payback period and savings associated with a given measure will vary depending on facility activities, configuration, size, location, and operating characteristics. Hence, the values presented in the Energy Guide are offered as guidelines. Wherever possible, this Energy Guide will provide a typical range of savings and payback periods for each measure found under varying conditions.

Although technological changes in equipment conserve energy, changes in staff behavior and attitude can also have a great impact. Energy efficiency training programs can help a company's staff incorporate energy efficiency practices into their day-to-day work routines. Personnel at all levels should be aware of energy use and company objectives for energy efficiency improvement. Often such information is acquired by lower-level managers but neither passed up to higher-level management nor passed down to staff (Caffal 1995). Energy efficiency programs with regular feedback on staff behavior, such as reward systems, have had the best results. Though changes in staff behavior (such as switching off lights or closing windows and doors) often save only small amounts of energy at one time, taken continuously over longer periods they can have a much greater effect than more costly technological improvements. Other staff actions such as the closing of fume hood sashes could result in significant and immediate improvement. A further discussion of energy management programs and practices is offered in section 5.1 of this Energy Guide.

Establishing formal management structures and systems for managing energy that focus on continuous improvement are important strategies for helping companies manage energy use and implement energy efficiency measures. The U.S. EPA's ENERGY STAR program has developed a framework for energy management based on the observed best practices of leading companies. Other management frameworks, such as ISO 14001, can be used to ensure better organizational management of energy. One ENERGY STAR partner noted that using energy management programs in combination with the ISO 14001 program has had a greater impact on conserving energy at its plants than any other strategy.

Table 4. Energy efficiency opportunities for the pharmaceutical industry, categorized by major activity area. Each entry refers to a specific section (number) in this Energy Guide.

Research and Development	Bulk Manufacturing
Energy Management (5.1) HVAC (5.2) Fume Hoods (5.3) Cleanrooms (5.4) Lighting (5.9)	Energy Management (5.1) HVAC (5.2) Cleanrooms (5.4) Motor Systems (5.5) Compressed Air Systems (5.6) Pumps (5.7) Refrigeration (5.8) Heat and Steam Distribution (5.10)
Formulation, Packaging and Filling	**Offices**
Energy Management (5.1) HVAC (5.2) Cleanrooms (5.4) Motor Systems (5.5) Compressed Air Systems (5.6) Pumps (5.7) Refrigeration (5.8) Lighting (5.9)	Energy Management (5.1) HVAC (5.2) Lighting (5.9) Miscellaneous (5.12)
Warehouses	**Miscellaneous**
Energy Management (5.1) HVAC (5.2) Motor Systems (5.5) Refrigeration (5.8) Lighting (5.9)	Energy Management (5.1) HVAC (5.2) Motor Systems (5.5) Lighting (5.9) Heat and Steam Distribution (5.10) Cogeneration (5.11) Miscellaneous (5.12)

5.1 Energy Management Systems and Programs

Improving energy efficiency should be approached from several directions. A strong, corporate-wide energy management program is essential. Ideally, such a program would include facility, operations, environmental, health, and safety, and management personnel. Energy efficiency improvements to cross-cutting technologies[7], such the use of energy efficient motors and the optimization of compressed air systems, present well-documented opportunities for energy savings. Optimizing system design and operations, such as minimizing laboratory ventilation, can also lead to significant reductions in energy use. In addition, production process can often be fine-tuned to produce similar savings.

[7] Cross-cutting technologies are defined as equipment that is commonly used in many different sectors, such as boilers, pumps, motors, compressed air systems, and lighting.

Energy management programs. Changing how energy is managed by implementing an organization-wide energy management program is one of the most successful and cost-effective ways to bring about energy efficiency improvements.

Energy efficiency does not happen on its own. A strong energy management program is required to create a foundation for positive change and to provide guidance for managing energy throughout an organization. Energy management programs also help to ensure that energy efficiency improvements do not just happen on a one-time basis, but rather are continuously identified and implemented in an ongoing process of continuous improvement. Furthermore, without the backing of a sound energy management program, energy efficiency improvements might not reach their full potential due to lack of a systems perspective and/or proper maintenance and follow-up.

In companies without a clear program in place, opportunities for improvement may be known but may not be promoted or implemented because of organizational barriers. These barriers may include a lack of communication among plants, a poor understanding of how to create support for an energy efficiency project, limited finances, poor accountability for measures, or organizational inertia to changes from the status quo. Even when energy is a significant cost, many companies still lack a strong commitment to improve energy management.

The U.S. EPA, through the ENERGY STAR program, works with leading industrial manufacturers to identify the basic aspects of an effective energy management program.[8] The major elements in a strategic energy management program are depicted in Figure 7.

A successful program in energy management begins with a strong organizational commitment to continuous improvement of energy efficiency. This involves assigning oversight and management duties to an energy director, establishing an energy policy, and creating a cross-functional energy team. Steps and procedures are then put in place to assess performance through regular reviews of energy data, technical assessments, and benchmarking. From this assessment, an organization is able to develop a baseline of energy use and set goals for improvement. Performance goals help to shape the development and implementation of an action plan.

An important aspect for ensuring the success of the action plan is involving personnel throughout the organization. Personnel at all levels should be aware of energy use and goals for efficiency. Staff should be trained in both skills and general approaches to energy efficiency in day-to-day practices. In addition, performance results should be regularly evaluated and communicated to all personnel, recognizing high achievement. Some examples of simple tasks employees can do are outlined in Appendix A.

Progress evaluation involves the regular review of both energy use data and the activities carried out as part of the action plan. Information gathered during the formal review process helps in setting new performance goals and action plans, and in revealing best practices. Once best practices are established, the goal of the cross-functional energy team should be to replicate these practices throughout the organization. Establishing a strong communications

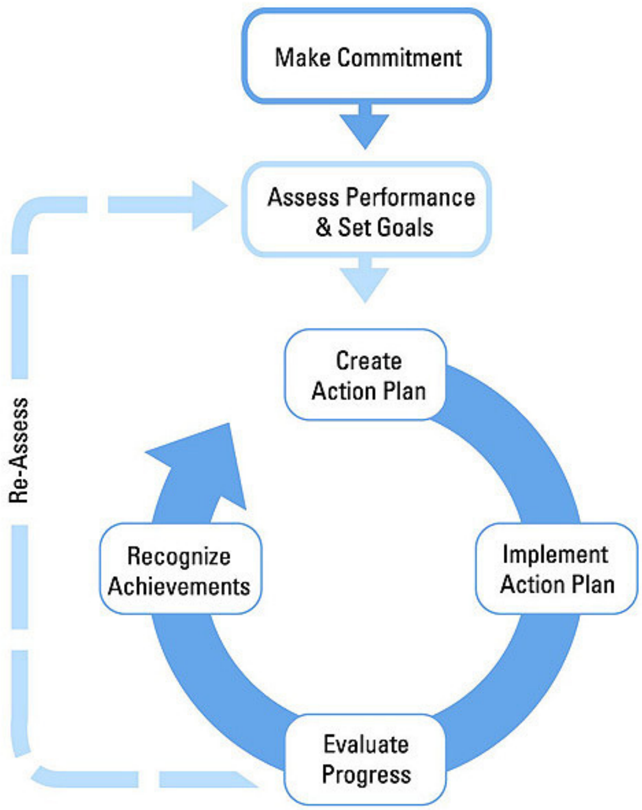
[8] Read more about strategic energy management at www.energystar.gov.

program and seeking recognition for accomplishments are also critical steps. Strong communication and receiving recognition help to build support and momentum for future activities.

A quick assessment of an organization's efforts to manage energy can be made by comparing its current energy management program against the ENERGY STAR Energy Program Assessment Matrix provided in Appendix B.[9]

Internal support for a business energy management program is crucial; however, support for business energy management programs can come from outside sources as well. Some utility companies work together with industrial clients to achieve energy savings. In these cases, utility personnel work directly with the company onsite.

Figure 7. Main elements of a strategic energy management program.



Energy monitoring systems. Energy monitoring systems and process control systems are key tools that play an important role in energy management and in reducing energy use. Such systems may include sub-metering, monitoring, and control systems. They can reduce the time required to perform complex tasks, often improve product and data quality as well as consistency, and optimize process operations. Monitoring and metering systems also play a

[9] Another useful reference for implementing energy management programs is the U.S. EPA and DOE sponsored report *Fifteen O&M Best Practices for Energy Efficient Buildings* (PECI 1999).

key role in alerting energy teams to problem areas and in assigning accountability for energy use. Additionally, such systems can be useful in corporate greenhouse gas accounting initiatives; they are also helpful in profiling energy use at ENERGY STAR partners. Typically, energy and cost savings are around 5% or more for many industrial applications of monitoring and control systems. These savings apply to plants without updated process control systems; many U.S. plants may already have modern process control systems in place to improve energy efficiency.

The Wyeth Fort Dodge Animal Health pharmaceutical manufacturing facility in Campinas, Brazil, installed a state-of-the-art metering, monitoring, and targeting system to help reduce electrical demand during peak periods. This project resulted in a 48% reduction in electricity use, a 10% reduction in facility utility costs, and increased energy awareness among employees (Wyeth 2004).

5.2 Heating, Ventilation, and Air Conditioning (HVAC) Systems

The components of HVAC systems generally include dampers, supply and exhaust fans, filters, humidifiers, dehumidifiers, heating and cooling coils, ducts, and various sensors (Cole 1998). In Table 3, it was estimated that the average percentage of electricity and fuel consumed by HVAC components in the pharmaceutical industry is around 65%.

Different spaces and building uses require different HVAC applications. For manufacturing facilities and some laboratory facilities in the U.S. pharmaceutical industry, HVAC components—as well as modifications to those components—are closely supervised by the U.S. FDA. Moreover, the U.S. pharmaceutical industry is required to meet a host of domestic and foreign standards (e.g., the U.S. Federal Code of Regulations, British Standards, and EU Standards). An effort to consolidate such standards into one unified set is currently underway at the International Organization of Standardization (ISO). As a result of such regulation, energy efficiency measures that affect the work environment must undergo a thorough review to ensure that proposed modifications will not affect regulatory compliance. The U.S. FDA requires companies to conform to cGMP (current Good Manufacturing Practices), which requires companies to document how they intend to design and operate a facility. While cGMP theoretically allows for new approaches, these new approaches would need to be defended. The additional defense (and risks associated with a delay in approval of building plans) may in some cases perpetuate less energy efficient designs.

When a company must retrofit an existing building to comply with new regulations, it is often advantageous to implement energy efficiency measures during the production downtime that occurs when facilities are being overhauled. However, for non-regulated buildings such as offices and warehouses, energy efficiency measures can be implemented independent of regulatory approvals that apply to production and R&D spaces.

A Novartis plant in Rzeszow (Poland) offers a good example of how investments in HVAC system efficiencies can lead to significant energy savings. At the Rzeszow plant, Novartis installed microprocessor controls on its HVAC system that could be programmed to better balance plant heating based on outside temperatures and also reduce heating loads on weekends. It is anticipated that this modification will lead to a 10% reduction in overall heating energy consumption. Novartis also invested in a more modern HVAC system for the plant's baby food filling process. The old HVAC system was comprised of convection heaters and heating fan systems. Novartis replaced this system with an integrated heating-and-ventilation system controlled by microprocessors, which offered both improved air quality and improved temperature regulation during both winter and summer seasons. This change has led to a dramatic improvement in both air quality and comfort. A further increase in power efficiency has been achieved through the installation of heat recovery filters at the system's air outlets, which offered expected energy savings of approximately 5% (Novartis 2004).

There are many energy efficiency measures that can be applied to HVAC systems; some of the most significant opportunities are discussed below. Additionally, there are many energy efficiency measures that apply to motors, compressed air systems, and heat and steam distribution systems that can also be leveraged to improve HVAC system efficiency. Measures for motors, compressed air systems, and heat and steam distribution systems are discussed in more detail in Sections 5.5, 5.6, and 5.9 of this Energy Guide.

Energy efficient system design. The greatest opportunities for energy efficiency exist at the design stage for HVAC systems in new industrial facilities. By sizing equipment properly and designing energy efficiency into a new facility, a pharmaceutical manufacturer can minimize the energy consumption and operational costs of its plant HVAC systems from the outset. This practice often saves money in the long run, as it is generally cheaper to install energy efficient HVAC equipment at building construction than it is to upgrade an existing building with an energy efficient HVAC system later on, especially if those upgrades lead to production downtime. Later HVAC modification may also require review and approval by the U.S. FDA, which can lead to further delays and production downtime.

The U.S. EPA's Laboratories for the 21st Century (Labs 21) program has compiled tips for the energy efficient design of new labs and cleanrooms, many of which can be applied to pharmaceutical industry facilities (U.S. EPA/DOE 2000). Further information on the Labs 21 Program can be found at http://www.labs21century.gov/.

Recommissioning. Before replacing HVAC system components to improve energy efficiency, the possibility of HVAC system recommissioning should be explored. Recommissioning is essentially the same process as commissioning, but applied to a building's existing HVAC, controls, and electrical systems (U.S. EPA 2004).

Commissioning is the process of verifying that a new building functions as intended and communicating the intended performance to the building management team. This usually occurs when a new building is turned over for occupancy. In practice, commissioning costs are not included in design fees and often compete with other activities. As a result, commissioning is seldom pursued properly. It is critical that the building is commissioned to ensure that energy performance and operational goals are met. To achieve this, ENERGY STAR recommends the following:

- Communicate your energy performance goals during commissioning to ensure that the design target is met. Encourage energy-use tracking that will allow performance comparisons to be made over time.
- Specify detailed commissioning activities in your project contracts. Seek separate funding for commissioning work to ensure that it is given the appropriate level of importance.
- Hire experts that specialize in building commissioning. Include the commissioning firm as part of the design team early in the project.
- Finalize and transfer a set of technical documents including manufacturers' literature for systems and components. Supplement technical literature with summaries of intended operation. Provide additional explanation for innovative design features.

Recommissioning involves a detailed assessment of existing equipment performance and maintenance procedures for comparison to intended or design performance and maintenance procedures, to identify and fix problem areas that might be hampering building energy efficiency. Recommissioning can be a cost-effective retrofit in itself, sometimes generating more savings than the cost of the retrofit measure. For example, recommissioning may help avoid the need to install new or additional equipment, leading to savings in capital investments.

The U.S. EPA’s ENERGY STAR Building Upgrade Manual (U.S. EPA 2004) recommends a stepwise approach to recommissioning, in which a series of strategically-ordered building “tune up” strategies are pursued in order. First lighting and supplemental loads should be assessed, then the building envelope, then controls, then testing, adjusting and balancing, then heat exchange equipment, and finally heating and cooling systems. Most of these steps relate to HVAC system components or factors that will directly affect HVAC system energy consumption (such as building envelope and lighting). For more information, the U.S. EPA’s ENERGY STAR Building Upgrade Manual (U.S. EPA 2004) should be consulted (see also http://www.energystar.gov). More details on many of the measures employed in recommissioning can be found in later sections of this Energy Guide.

In 2002, Pfizer implemented an HVAC recommissioning project in four buildings at its Morris Plains, New Jersey, location (Dome-Tech 2005a). To date, Pfizer has experienced a 21% net decrease in energy consumption per degree-day as a result of this project.

At Ethicon’s Somerville, New Jersey, location, a recommissioning project on a 180,000 ft^2 multi-use facility identified 231 opportunities for energy conservation and reduction (Dome-Tech 2005b). This recommissioning project involved design and installation reviews, data logging to identify areas of non-conformance, physical inspection of air handlers, and verification of HVAC system balance and air flows to various spaces (among other efforts). Project implementation costs were $53,000; annual savings in gas and electricity amounted to $48,000, leading to a payback period of just 1.1 years.

Energy monitoring and control systems. An energy monitoring and control system supports the efficient operation of HVAC systems by monitoring, controlling, and tracking system energy consumption. Such systems continuously manage and optimize HVAC system energy consumption while also providing building engineers and energy managers with a valuable diagnostic tool for tracking energy consumption and identifying potential HVAC system problems (U.S. EPA/DOE 2000). Several industrial case studies from the United States indicate that the average payback period for HVAC control systems is about 1.3 years (IAC 2003).

Non-production hours set-back temperatures. Setting back building temperatures (i.e., turning building temperatures down in winter or up in summer) during periods of non-use, such as weekends or non-production times, can lead to significant savings in HVAC energy consumption. Similarly, reducing ventilation in cleanrooms and laboratories during periods of non-use can also lead to energy savings. In recent studies of laboratories and cleanrooms in the pharmaceutical and similar industries, HVAC systems were found to account for up to two-thirds of facility energy consumption (Tschudi and Xu 2003). Thus, scaling back HVAC energy consumption during periods of non-use can have a major impact.

At Merck's Rahway, New Jersey, laboratory facilities, HVAC systems are designed with once-through air exchange based on safety considerations. To improve the energy efficiency of these systems, Merck utilized control technologies to lower selected room temperatures from 72°F to 64°F during nights and weekends. An interlock with room lighting overrides the set-back. This control strategy was implemented for rooms where lower temperatures would not impact scientific equipment, and covered 150 individual laboratory spaces encompassing over 350,000 ft^2 of floor space. The energy savings associated with this project totaled nearly 30,000 MBtu per year. The energy-related carbon dioxide (CO_2) emissions avoided through this project amounted to over 1,700 tons per year (Merck 2005).

Duct leakage repair. Duct leakage can waste significant amounts of energy in HVAC systems. Measures for reducing duct leakage include installing duct insulation and performing regular duct inspection and maintenance, including ongoing leak detection and repair. According to studies by Lawrence Berkeley National Laboratory, repairing duct leaks in industrial and commercial spaces could reduce HVAC energy consumption by up to 30%. One commercial building in Apple Valley, California, adopted a technique called the mobile aerosol-sealant injection system (MASIS) to reduce duct leakage. The application of MASIS resulted in a reduction in overall duct leakage from 582 cfm to 74 cfm, leading to a 34% increase in the overall efficiency of the building's HVAC system (Carrier Aeroseal 2002).

Discharge air temperature management. In facilities with make-up air handling systems, energy can be wasted when cooled make-up air must be reheated. By setting higher discharge air temperatures when demand for cooling decreases, unnecessary reheating of the make-up air supply can be reduced. At Genentech's Vacaville facility, a new control system was implemented to reset the discharge air temperature from 55°F to 60°F under periods of low cooling demand. This temperature adjustment prevented overcooling and subsequent unnecessary reheating of supply air, thereby saving chilled water and steam plant energy. This measure was expected to have annual energy cost savings of around $150,000 per year (CIEE 2000a).

Variable-air-volume (VAV) systems. Variable-air-volume systems adjust the rate of air flow into a room or space based on the current air flow requirements of that room or space, and therefore work to optimize the air flow within HVAC ductwork. By optimizing air flow, the loads on building air handling units can be reduced, thereby leading to reduced electricity consumption.

Adjustable speed drives (ASDs).[10] Adjustable speed drives can be installed on variable-volume air handlers, as well as recirculation fans, to match the flow and pressure requirements of air handling systems precisely. Energy consumed by fans can be lowered considerably since they are not constantly running at full speed. Adjustable speed drives can also be used on chiller pumps and water systems pumps to minimize power consumption based on system demand.

The Louis Stokes Laboratories of the U.S. National Institutes of Health recently implemented a VAV system with adjustable speed drives (ASDs). The ASDs control the speed of HVAC supply and exhaust fans 25% more efficiently than the standard inlet vane controls that were used the past. Although the VAV system was a more complicated and expensive control system than the previous system, the VAV system used 30-50% less energy than the previous system did and thus led to significant energy cost savings over time (U.S. EPA/DOE 2001b). The VAV also reduced the volume of air delivered when the building is unoccupied, from a maximum volume of 400,000 cfm, or 15 air changes per hour (ACH), to 160,000 cfm, or 6 ACH, delivering further energy savings. Similarly, a VAV system installed at the Fred Hutchinson Cancer Research Center in Seattle, Washington, reduced necessary air changes from 10 ACH down to 6 ACH (U.S. EPA/DOE 2001a).

Heat recovery systems. Heat recovery systems reduce the energy required to heat or cool facility intake air by harnessing the thermal energy of the facility's exhaust air. Common heat recovery systems include heat recovery wheels, heat pipes, and run-around loops. For areas requiring 100% make-up air, studies have shown that heat recovery systems can reduce a facility's heating/cooling cost by about 3% for each degree (Fahrenheit) that the intake air is raised/lowered. The payback period is typically three years or less (Tetley 2001). Heat wheels installed at the Whitehead Biomedical Research Building in Atlanta, Georgia, demonstrated a heat exchange efficiency of 75% and a payback period of less than 4 years (U.S. EPA/DOE 2003). The efficiency of heat pipes is in the 45-65% range (U.S. EPA/DOE 2003), while the efficiency of run-around loops can be slightly higher, in the 55-65% range (U.S. EPA/DOE 2001a).

In 2004, Merck in Rahway, New Jersey, installed a glycol run-around loop system to recover heat from HVAC exhaust air at a 37,000 ft^2 laboratory building. After installation, the building was able to pre-heat and pre-cool up to 120,000 cfm of outside air with recovered energy. The energy savings associated with this measure amounted to roughly 265 MBtu per year, which led to avoided CO_2 emissions of over 30 tons per year (Merck 2005).

[10] Several terms are used in practice to describe a system that permits a mechanical load to be driven at user-selected speeds, including adjustable speed drives (ASDs), variable speed drives (VSDs), adjustable frequency drives (AFDs), and variable frequency drives (VFDs). The term ASD is used throughout this Energy Guide for consistency.

HVAC chiller efficiency improvement. The efficiency of chillers can be improved by lowering the temperature of the condenser water, thereby increasing the chilled water temperature differential. This can reduce pumping energy requirements. Another possible efficiency measure is the installation of separate high-temperature chillers for process cooling (Tschudi and Xu 2003).

Sizing chillers to better balance chiller load with demand is also an important energy efficiency strategy. At Genentech's facility in Vacaville, California, two 1,400 ton chillers and one 600 ton chiller were chosen instead of three equally-sized chillers. This selection was made in an effort to operate the chillers at as close to full load as possible, where they are most efficient. The two larger chillers are run at full load and the smaller chiller is run to supply additionally cooling only on an as-needed basis, reducing energy needs. The cost savings associated with this chiller selection strategy were estimated to be $113,250 per year (CIEE 2000a).

Fan modification. Changing the size or shape of the sheaves of a fan can help to optimize fan efficiency and airflow, thereby reducing energy consumption. At a Toyota plant, the sheaves of fans were optimized in lieu of installing ASDs on fans. Toyota found better savings and payback periods with sheave modification than they anticipated to experience from ASDs (Toyota 2002).

Efficient exhaust fans. Exhaust fans are standard components in any HVAC system. Mixed flow impeller exhaust fans offer an efficient alternative to traditional centrifugal exhaust fans. Mixed flow impeller fans are typically 25% more efficient that centrifugal fans, and can also be cheaper to install and maintain. The expected payback period for this measure is around 2 years (Tetley 2001).

Cooling water recovery. If available, secondary cooling water from municipal sources can be leveraged to reduce chiller energy consumption. In Washington, Boeing partnered with Puget Sound Power and Light and the King County Department of Metropolitan Services to recycle secondary treated cooling water into its chiller system. By doing so, Boeing reduced its water consumption by 48 million gallons per year and projected savings of 20% in its cooling energy consumption (Michaelson and Sparrow 1995). As an additional benefit, Boeing also expected to save on refrigerant and treatment chemicals for its cooling tower water.

Solar air heating. Solar air heating systems, such as Solarwall®, use conventional steel siding painted black to absorb solar radiation for insulation. Fresh air enters the bottom of the panels where it is heated as it passes over the warm absorber. Fans distribute the air. Using this technology, Ford Motor Company's Chicago Stamping plant turned the south wall of its plant into a huge solar collector (CREST 2001). Energy savings were estimated to be over $300,000 per year compared to conventional gas air systems. Capital costs were $863,000 ($14.90 per square foot, including installation) resulting in a payback period of less than 3 years. In addition to energy savings, the system provides clean fresh air for its employees, evens out hot and cold spots in the plant and reduces emissions. However, this measure is only of interest for buildings in cold climates, and the potential benefits should be analyzed based on the local conditions of each site.

Building reflection. Use of a reflective coating on the roof of buildings in sunny, hot climates can save on air conditioning costs inside. Two medical offices in Northern California used reflective roofs on their buildings; one reduced air conditioning demand by 8%, the other reduced air conditioning demand by 12% (Konopacki et al., 1998). For colder climates, heat lost due to cool roofs (in winter, for example) also needs to be taken into account, and often negates savings. In addition to location and weather, other primary factors influence energy savings, such as roof insulation, air conditioning efficiency, and building age. Reflective roof materials are available in different forms and colors.

Roof gardens on a flat roof improve the insulation of buildings against both hot and cold by providing both heat (in winter) and air conditioning (in summer). In winter, green roofs can freeze, so they carry a slight heating penalty but they still yield net energy savings (Holtcamp 2001). In addition, a roof garden can increase the lifetime of the roof, provide and reduce runoff, and reduce air pollution and dust. Today, Germany installs over 10 million ft^2 of green roofs a year, helped in part by economic incentives (Holtcamp 2001). The Gap Headquarters in San Bruno (California) installed green roofs in 1997 (Greenroofs.com 2001). In addition to saving energy and lasting longer than traditional roofs, a roof garden absorbs rain, slowing run-off to local storm drains.

Other simple options for decreasing building HVAC energy use exist for certain conditions. Shade trees reduce cooling for hot climates. Shade trees should be deciduous trees (providing shade in the summer and none in the winter) and planted on the west and southwest sides of the building (based on the path of the summer sun) (McPherson and Simpson 1995). Trees planted on the north side of the building in cold climates can reduce heating in winter by shielding the building from the wind. Vines can provide both shade and wind shielding.

Building insulation. Adding insulation to a facility will nearly always result in the reduction of utility bills. Much of the existing building stock in the United States is not insulated to the best level. Older buildings are likely to use more energy than newer ones, leading to very high heating and air conditioning bills. Even for a new building, adding insulation may save enough through reduced utility bills to pay for itself within a few years (U.S. DOE 2002a).[11]

Various states have regulations and guidelines for building insulation, for example, California's Energy Efficiency Standards for Residential and Nonresidential Buildings (Title 24) (CEC 2001). Going beyond regulated insulation levels may be economically beneficial and should be considered as part of the design of a new building, as well as for reconstruction of existing buildings. For refrigerated warehouses, much higher levels of insulation are preferred (see also section 5.8).

[11] For homes, ENERGY STAR has established guidelines on the preferred level of insulation for different climate zones (see: http://www.energystar.gov/index.cfm?c=home_sealing.hm_improvement_insulation_table).

Low-emittance (Low-E) windows. Low-emittance windows are another effective strategy for improving building insulation. Low-emittance windows can lower the heat transmitted into a building and therefore increase its insulating ability. There are two types of Low-E glass, high solar transmitting (for regions with higher winter utility bills) and low solar transmitting (for regions with higher summer utility bills) (U.S. DOE 1997). The U.S. DOE supports the development of new window and glazing technology, while ENERGY STAR provides a selection of rated Low-E windows. New window and glazing technology is being developed continuously around the world.[12]

5.3 Fume Hoods

Fume hoods are commonly installed in R&D laboratory facilities in the pharmaceutical industry. Fume hoods capture, contain, and exhaust hazardous gases generated by laboratory activities and industrial process and therefore protect workers from breathing harmful substances (Mills and Sartor 2004). The energy required to heat and cool make-up air for laboratory fume hoods can account for a significant fraction of laboratory HVAC energy consumption. Fume hoods are often operated at high air exchange rates in an effort to guarantee the safety of occupants in the facility. However, significant energy savings can often be realized by using low-flow fume hoods and variable flow exhaust systems.

Improved storage/housekeeping. Fume hoods are often used as temporary storage spaces for chemicals and instruments in laboratory environments. However, this practice can require that fume hood exhaust systems run continuously, leading to unnecessarily high energy consumption. Improved housekeeping and storage practices, whereby chemicals and instruments are always kept in their proper storage locations and unused fume hoods are kept closed, would help to reduce hood energy consumption.

Restriction of sash openings. The restriction of fume hood sash openings reduces the volumetric flow rate necessary to maintain a constant airflow velocity across the face of the hood. A reduced volumetric flow requirement can facilitate lower energy consumption in variable flow hoods. A fume hood's sash opening can be limited either by restricting the vertical sash movement or by using a horizontal sash to block the hood's entrance (Mills and Sartor 2004). Furthermore, sashes on unattended fume hoods should remain closed whenever possible. In an assumed laboratory with 48 fume hoods, it was estimated that by closing the sashes on unattended fume hoods in a VAV system (see discussion on VAV hoods below), energy savings would be around $3,200 per year (RC Associates 2002).

Promotion of a vortex in tops of fume hoods. A "bi-stable" vortex can enhance a fume hood's containment performance while also reducing its direct and indirect energy consumption. The vortex is promoted and maintained within the hood via adjustable panels in the top of the hood. According to one manufacturer, the bi-stable vortex hood provides maximum containment but consumes only 40% of the energy required by conventional hoods (United Lab Equipment 2001). Additionally, the bi-stable vortex hood can lower necessary air exchange rates, leading to savings in facility HVAC energy consumption as well.

[12] For more information on Low-E windows see: http://www.efficientwindows.org/.

Variable-air-volume (VAV) hoods. Constant-air-volume (CAV) hoods, which maintain a constant volumetric exhaust rate regardless of hood face airflow requirements, have been the mainstay in many U.S. laboratories. Variable-air-volume hoods, which employ ASDs and direct digital control systems to adjust exhaust airflow based on face velocity requirements, can offer considerable energy savings compared to CAV hoods. Variable-air-volume hoods save energy by minimizing the volumetric flow rate of hood exhaust, which can lead to significant reductions in the amount of exhaust air that must be conditioned by a building's HVAC system (Mills and Sartor 2004). The Louis Stokes Laboratories of the U.S. National Institutes of Health recently installed VAV hoods and experienced savings in energy consumption of up to 70% compared with conventional CAV hoods (U.S. EPA/DOE 2001b). Pharmacia also adopted VAV hoods, which cut exhaust airflow volume by over 50% when hood sashes are closed, leading to reductions in the energy required to condition make-up air (U.S. EPA/DOE 2002a).

Berkeley Hood. The "Berkeley Hood," developed by Lawrence Berkeley National Laboratory, has several advantages over traditional fume hoods (Bell et al. 2003). First, the Berkeley Hood reduces exhaust airflow requirements by 50-70%, which can result in energy savings of around $2,100 per year per fume hood. Exhaust airflow requirements are reduced via low velocity fans installed at the top and bottom of the hood sash, which form an "air divider" between the hood's interior and exterior, thereby reducing interior airflow requirements. Second, it offers lower installation costs than traditional VAV fume hoods. Third, its high efficiency lighting system can lower the electricity required for hood lighting by up to 50%.[13]

The Berkeley Hood is not yet commercially available. One of the primary barriers to its commercialization are current Occupational Safety and Health Administration (OSHA) standards that prescribe a fume hood face velocity of at least 100 feet per minute rather than prescribing air quality criteria for containment performance. However, future comparisons of the Berkeley Hood's containment performance to that of standard fume hoods should prove its adequacy.

5.4 Cleanrooms

A cleanroom can be defined as an enclosed area in which ambient conditions—including airborne particles, temperature, noise, humidity, air pressure, air motion, vibration, and lighting—are strictly controlled. A significant portion of floor space in pharmaceutical and biotechnology facilities can be occupied by cleanrooms (Mills et al. 1996). In general, the largest consumers of energy in cleanrooms are the HVAC system (e.g., systems for chilled water, hot water, and steam) and process machinery. A recent study found that HVAC systems accounted for 36-67% of cleanroom energy consumption (Tschudi et al. 2001). Another recent study estimated the following energy distribution for cleanroom operation: 56% for cooling, 36% for heating, 5% for fans, and 3% for pumps (IEC 2002).

In the U.S. pharmaceutical industry, proper cleanroom filtration and pressure differentials have to be maintained to meet strict U.S. FDA requirements. Many issues regarding the

[13] Further information on the Berkeley Hood can be found at http://ateam.lbl.gov/hightech/fumehood/fhood.html.

optimization of HVAC systems have been addressed in the preceding section; additional energy efficiency measures specific to cleanrooms are discussed below.

The Labs 21 Program has developed an online energy benchmarking tool for cleanroom and laboratory spaces (U.S. EPA/DOE 2005). Benchmarking can help to provide information on the performance of a given facility, relative to that of peer facilities, by comparing the facility energy performance. Furthermore, this benchmarking process accounts for differences in air quality, size, and other system parameters that might exist between different facilities.

Reduced recirculation air change rates. The rate of clean room air recirculation can sometimes be reduced while still meeting quality control and regulatory standards. A simulation study of a cleanroom in Ireland showed that it was possible to reduce the hourly air change rates of air recirculation units, which would lead to significant cost savings from reduced fan energy and resultant heat load (IEC 2002).

Improved air filtration quality and efficiency. High Efficiency Particulate Air (HEPA) filters and Ultra Low Penetration Air (ULPA) filters are commonly used in the pharmaceutical industry to filter make-up and recirculated air. The adoption of alternative filter technologies might allow for lower energy consumption. For example, new air filtration technologies that trap particles in the ultra-fine range (0.001-0.1 microns), a range for which current filter technologies are not effective, might reduce the energy necessary for reheating/re-cooling cleanroom air (CADDET 1999). Low pressure drop filters can also offer energy savings: in a test conducted by the Swedish National Board for Industrial and Technical Development (Nutek), some air handling unit filters were found to maintain lower pressure drops and to reduce air handling energy consumption to half that required by normal filters. The annual energy savings associated with the top-performing filters in the Nutek tests was around $46 per filter (Camfil 1997).

Optimized chilled water systems. Chilled water systems that supply cleanrooms are rarely optimized for energy efficiency (Tschudi et al. 2002). Chilled water system efficiency improvement has been well documented in the literature; however, many designers and operators of pharmaceutical facilities could benefit from a review of the published recommendations. Some suggestions for improving chilled water system performance have been discussed in Section 5.2.

Cooling towers. In many instances, water cooling requirements can be met by cooling towers in lieu of water chillers. Water towers can cool water much more efficiently than chillers and can therefore reduce the overall energy consumption of cleanroom HVAC systems. Operating multiple cooling towers at reduced fan speed rather than operating fewer towers at full speed is a further option for lowering cooling water energy consumption (Tschudi and Xu 2003).

Reduction of cleanroom exhaust. The energy required to heat and cool cleanroom make-up air accounts for a significant fraction of cleanroom HVAC energy consumption. Measures to reduce cleanroom exhaust airflow volume can therefore lead to significant energy savings. Such measures include the use of efficient fume hood technologies as described in the previous section. Additionally, measures aimed at heat recovery in cleanroom exhaust systems might also be effective at reducing overall HVAC system energy consumption (see Section 5.2).

Declassification. Occasionally, a cleanroom is classified at a higher cleanliness level than is necessary for its current use, either due to conservative design or to a transition in its production characteristics over time. A simple efficiency measure that might be available for such cleanrooms is to declassify them from a higher class of cleanliness to a lower class of cleanliness, provided that the lower class still meets production requirements for contamination control and air change rates. For example, at a Motorola facility in Northbrook, Illinois, the classification of a cleanroom space was reduced from class 10,000 to class 100,000 in order to lower operation costs. As a result, the airflow rate was lowered, leading to annual savings of over $150,000 at a payback period of only 7 months (CIEE 2000c).

5.5 Motors and Motor Systems[14]

Motors and drives are used throughout the pharmaceutical industry to operate HVAC systems, to drive laboratory or bulk manufacturing equipment (including mixers, pumps, centrifuges, and dryers), and for transport and equipment operation in the formulation and packaging stages. The energy efficiency measures described in the following section apply to any system that uses motors. Where appropriate, specific examples are listed detailing to which system each measure has already been applied, and to what success.

When considering energy efficiency improvements to a facility's motor systems, it is important to take a "systems approach." A systems approach strives to optimize the energy efficiency of entire motor systems (i.e., motors, drives, driven equipment such as pumps, fans, and compressors, and controls), not just the energy efficiency of motors as individual components. A systems approach analyzes both the energy supply and energy demand sides of motor systems as well as how these sides interact to optimize total system performance, which includes not only energy use but also system uptime and productivity.

A systems approach typically involves the following steps. First, all applications of motors in a facility should be located and identified. Second, the conditions and specifications of each motor should be documented to provide a current systems inventory. Third, the needs and the actual use of the motor systems should be assessed to determine whether or not motors are properly sized and also how well each motor meets the needs of its driven equipment. Fourth, information on potential repairs and upgrades to the motor systems should be collected, including the economic costs and benefits of implementing repairs and upgrades to enable the energy efficiency improvement decision-making process. Finally, if upgrades are

---

[14] The U.S. DOE's Industrial Technologies Program provides a variety of resources for improving the efficiency of industrial motor systems, which can be consulted for more detailed information on many of the measures presented in this section. For a collection of tips, tools, and industrial case studies on motor efficiency, visit the Industrial Technologies Program's *BestPractices* Motors, Pumps, and Fans website at: http://www1.eere.energy.gov/industry/bestpractices/systems.html. Furthermore, the Motor Decisions Matter[SM] Campaign also provides a number of excellent resources for improving motor system efficiency (http://www.motorsmatter.org/).

pursued, the performance of the upgraded motor systems should be monitored to determine the actual costs savings (SCE 2003).

The motor system energy efficiency measures below reflect important aspects of this systems approach, including matching motor speeds and loads, proper motor sizing, and upgrading system components. Compressed air systems and pumps are both discussed in more detail in Sections 5.6 and 5.7, respectively.

Motor management plan. A motor management plan is an essential part of a plant's energy management strategy. Having a motor management plan in place can help companies realize long-term motor system energy savings and will ensure that motor failures are handled in a quick and cost effective manner. The Motor Decisions Matter^{SM} Campaign suggests the following key elements for a sound motor management plan (MDM 2007):

1. Creation of a motor survey and tracking program.
2. Development of guidelines for proactive repair/replace decisions.
3. Preparation for motor failure by creating a spares inventory.
4. Development of a purchasing specification.
5. Development of a repair specification.
6. Development and implementation of a predictive and preventive maintenance program.

The Motor Decisions Matter^{SM} Campaign's *Motor Planning Kit* contains further details on each of these elements (MDM 2007).

Strategic motor selection. Several factors are important when selecting a motor, including motor speed, horsepower, enclosure type, temperature rating, efficiency level, and quality of power supply. When selecting and purchasing a motor, it is also critical to consider the life-cycle costs of that motor rather than just its initial purchase and installation costs. Up to 95% of a motor's costs can be attributed to the energy it consumes over its lifetime, while only around 5% of a motor's costs are typically attributed to its purchase, installation, and maintenance (MDM 2007). Life cycle costing (LCC) is an accounting framework that allows one to calculate the total costs of ownership for different investment options, which leads to a more sound evaluation of competing options in motor purchasing and repair or replacement decisions. A specific LCC guide has been developed for pump systems (Fenning et al. 2001), which also provides an introduction to LCC for motor systems.

The selection of energy-efficient motors can be an important strategy for reducing motor system life-cycle costs. Energy-efficient motors reduce energy losses through improved design, better materials, tighter tolerances, and improved manufacturing techniques. With proper installation, energy-efficient motors can also run cooler (which may help reduce facility heating loads) and have higher service factors, longer bearing life, longer insulation life, and less vibration.

To be considered energy efficient in the United States, a motor must meet performance criteria published by the National Electrical Manufacturers Association (NEMA). The

Consortium for Energy Efficiency (CEE) has described the evolution of standards for energy-efficient motors in the United States, which is helpful for understanding "efficient" motor nomenclature (CEE 2007):

- NEMA Energy Efficient (NEMA EE) was developed in the mid-1980s to define the term "energy efficient" in the marketplace for motors. NEMA Standards Publication No. MG-1 (Revision 3), Table 12-11 defines efficiency levels for a range of different motors (NEMA 2002).

- The Energy Policy Act of 1992 (EPACT) required that many commonly used motors comply with NEMA "energy efficient" ratings if offered for sale in the United States.

- In 1996, the CEE Premium Efficiency Criteria specification was designed to promote motors with higher efficiency levels than EPACT required, for the same classes of motors covered by EPACT. The CEE efficiency levels specified were generally two NEMA efficiency bands (Table 12-10, NEMA MG-1 Revision 3) above those required by EPACT.

- In 2001, the NEMA Premium® Efficiency Electric Motor specification was developed to address confusion with respect to what constituted the most efficient motors available in the market. This specification was developed by NEMA, CEE, and other stakeholders, and was adapted from the CEE 1996 criteria. It currently serves as the benchmark for premium energy efficient motors. NEMA Premium® also denotes a brand name for motors which meet this specification. Specifically, this specification covers motors with the following attributes:

    - Speed: 2, 4, and 6 pole
    - Size: 1-500 horsepower (hp)
    - Design: NEMA A and B
    - Enclosure type: open and closed
    - Voltage: low and medium voltage
    - Class: general, definite, and special purpose

The choice of installing a premium efficiency motor strongly depends on motor operating conditions and the life cycle costs associated with the investment. In general, premium efficiency motors are most economically attractive when replacing motors with annual operation exceeding 2,000 hours/year. However, software tools such as MotorMaster+ (see Appendix C) can help identify attractive applications of premium efficiency motors based on the specific conditions at a given plant.

Sometimes, even replacing an operating motor with a premium efficiency model may have a low payback period. According to data from the Copper Development Association, the upgrade to high-efficiency motors, as compared to motors that achieve the minimum efficiency as specified by EPACT, can have paybacks of less than 15 months for 50 hp motors (CDA 2001). Payback times will vary based on size, load factor, running time, local energy costs, and available rebates and/or incentives (see Appendix C). Given the quick payback time, it usually makes sense to by the most efficient motor available (U.S. DOE and CAC 2003).

NEMA and other organizations have created the Motor Decisions Matter[SM] campaign to help industrial and commercial customers evaluate their motor repair and replacement options, promote cost-effective applications of NEMA Premium® motors and "best practice" repair, and support the development of motor management plans before motors fail.

Twenty-three case studies on high-efficiency motor installations in the U.S. pharmaceutical industry, including upgrades and replacements, showed an average payback period of less than 3 years (IAC 2003). [15]

At Minnesota Mining and Manufacturing (3M), an in-house motor system performance optimization was conducted in Building 123. Building 123 houses pilot plants, mechanical and electrical maintenance shops, laboratories, and support functions. An evaluation of all electric motors larger than 1.5 hp in the building identified 50 older, standard-efficiency motors that operated more than 6,000 hours per year. Twenty-eight of these motors were exchanged to energy efficient motors. An energy efficiency improvement of 2-5% for each motor replacement was expected. Other measures were also taken, such as sheave changes to reduce the driven load, downsizing of motors to better match system requirements, and repair and cleaning of components to reduce efficiency losses. The payback period for this project was estimated at 3.1 years (U.S. DOE 2002b).

In some cases, it may be cost-effective to rewind an existing energy efficient motor, instead of purchasing a new motor. As a rule of thumb, when rewinding costs exceed 60% of the costs of a new motor, purchasing the new motor may be a better choice (MDM 2007). When rewinding a motor, it is important to choose a motor service center that follows best practice motor rewinding standards in order to minimize potential efficiency losses. An ANSI-approved recommended best practice standard has been offered by the Electric Apparatus Service Association (EASA) for the repair and rewinding of motors (EASA 2006). When best rewinding practices are implemented, efficiency losses are typically less than 0.5% to 1% (EASA 2003). However, poor quality rewinds may result in larger efficiency losses. It is therefore important to inquire whether the motor service center follows EASA best practice standards (EASA 2006).

Maintenance. The purposes of motor maintenance are to prolong motor life and to foresee a motor failure. Motor maintenance measures can be categorized as either preventative or predictive. Preventative measures, the purpose of which is to prevent unexpected downtime of motors, include electrical consideration, voltage imbalance minimization, load consideration, and motor ventilation, alignment, and lubrication. The purpose of predictive motor maintenance is to observe ongoing motor temperature, vibration, and other operating data to

[15] The Industrial Assessment Center (IAC) database contains case study data for a wide range of industrial energy efficiency measures. It gives a wide variety of information, including implementation costs and savings for each case study. Using the IAC database, the average payback period for all 23 case studies was calculated. In order to accurately represent applicable technology for the pharmaceutical industry, only data from the SIC codes that pertained to the pharmaceutical industry were used in this calculation.

identify when it becomes necessary to overhaul or replace a motor before failure occurs (Barnish et al. 1997). The savings associated with an ongoing motor maintenance program are significant, and could range from 2% to 30% of total motor system energy use (Efficiency Partnership 2004).

Properly sized motors. Motors that are sized inappropriately result in unnecessary energy losses. Where peak loads on driven equipment can be reduced, motor size can also be reduced. Replacing oversized motors with properly sized motors saves, on average for U.S. industry, 1.2% of total motor system electricity consumption (Xenergy 1998). Higher savings can often be realized for smaller motors and individual motor systems.

To determine the proper motor size, the following data are needed: load on the motor, operating efficiency of the motor at that load point, the full-load speed of the motor to be replaced, and the full-load speed of the replacement motor. The U.S. DOE's BestPractices program provides a fact sheet that can assist in decisions regarding replacement of oversized and under loaded motors (U.S. DOE 1996). Additionally, software packages such as MotorMaster+ (see Appendix C) can aid in proper motor selection.

Adjustable speed drives (ASDs). Adjustable-speed drives better match speed to load requirements for motor operations, and therefore ensure that motor energy use is optimized to a given application. Adjustable-speed drive systems are offered by many suppliers and are available worldwide. Worrell et al. (1997) provide an overview of savings achieved with ASDs in a wide array of applications; typical energy savings are shown to vary between 7% and 60%. Four case studies in the U.S. pharmaceutical industry have demonstrated an average payback period for ASDs of less than 2 years (IAC 2003). These four case studies included the installation of ASDs on cooling tower fans, ventilation equipment, and a dust collector motor.

Genentech installed ASDs on VAV air handlers in its Vacaville, California, facility, leading to significant reductions in energy consumption. The annual energy cost savings associated with this measure were expected to be around $23,000 per year (CIEE 2000a). At Hine Design in Sunnyvale, California, ASDs and related controls were installed on cleanroom recirculation fans, leading to expected energy savings of $36,000 per year with a simple payback period of 1.5 years (CIEE 2000b).

Power factor correction. Inductive loads like transformers, electric motors, and HID lighting may cause a low power factor. A low power factor may result in increased power consumption, and hence increased electricity costs. The power factor can be corrected by minimizing idling of electric motors (a motor that is turned off consumes no energy), replacing motors with premium-efficient motors (see above), and installing capacitors in the AC circuit to reduce the magnitude of reactive power in the system.

Minimizing voltage unbalances. A voltage unbalance degrades the performance and shortens the life of three-phase motors. A voltage unbalance causes a current unbalance, which will result in torque pulsations, increased vibration and mechanical stress, increased losses, and motor overheating, which can reduce the life of a motor's winding insulation. Voltage unbalances may be caused by faulty operation of power factor correction equipment, an unbalanced transformer bank, or an open circuit. A rule of thumb is that the voltage unbalance at the motor terminals should not exceed 1%. Even a 1% unbalance will reduce motor efficiency at part load operation, while a 2.5% unbalance will reduce motor efficiency at full load operation.

For a 100 hp motor operating 8,000 hours per year, a correction of the voltage unbalance from 2.5% to 1% will result in electricity savings of 9,500 kWh or almost $500 at an electricity rate of $0.05/kWh (U.S. DOE 2005).

By regularly monitoring the voltages at the motor terminal and through regular thermographic inspections of motors, voltage unbalances may be identified. It is also recommended to verify that single-phase loads are uniformly distributed and to install ground fault indicators as required. Another indicator that a voltage unbalance may be a problem is 120 Hz vibration, which should prompt an immediate check of voltage balance (U.S. DOE 2005). The typical payback period for voltage controller installation on lightly loaded motors in the United States is 2.6 years (IAC 2003).

Replacement of belt drives. Inventory data suggests that 4% of pumps have V-belt drives, many of which can be replaced with direct couplings to save energy (Xenergy 1998). Based on assessments in several industries, the savings associated with V-belt replacement are estimated at 4%. Investment costs are estimated at $0.10/kWh-saved with a simple payback period up to 2 years.

5.6 Compressed Air Systems

Compressed air generally represents one of the most inefficient uses of energy in U.S. industry due to poor system efficiency. Typically, the efficiency of a compressed air system—from compressed air generation to end use—is only around 10% (U.S. DOE and CAC 2003). Because of this inefficiency, if compressed air is used, it should be of minimum quantity for the shortest possible time; it should also be constantly monitored and weighed against potential alternatives.

Many opportunities to reduce energy consumption in compressed air systems are not prohibitively expensive; payback periods for some options can be extremely short. Energy savings from compressed air system improvements can range from 20% to 50% of total system electricity consumption (McKane et al. 1999). Common energy efficiency measures for industrial compressed air systems are discussed below. Additionally, many motor-directed measures, which were discussed in Section 5.5, can also be applied to compressors to reduce their energy consumption.

System improvements. Adding additional compressors should be considered only after a complete system evaluation. In many cases, compressed air system efficiency can be managed and reconfigured to operate more efficiently without purchasing additional compressors. System improvements utilize many of the energy efficiency measures for compressors discussed below. Compressed air system service providers offer integrated services both for system assessments and for ongoing system maintenance needs, alleviating the need to contact several separate firms. The Compressed Air Challenge®

(http://www.compressedairchallenge.org) offers extensive training on the systems approach, technical publications, and free web-based guidance for selecting the right integrated service provider. Also provided are guidelines for walk-through evaluations, system assessments, and fully instrumented system audits (CAC 2002).

Maintenance. Inadequate maintenance can lower compression efficiency and increase air leakage or pressure variability, as well as lead to increased operating temperatures, poor moisture control, and excessive contamination. Improved maintenance will reduce these problems and save energy. Proper maintenance includes the following (U.S. DOE and CAC 2003; Scales and McCulloch 2007):

- *Ongoing filter inspection and maintenance.* Blocked filters increase the pressure drop across the filter, which wastes system energy. By inspecting and periodically cleaning filters, filter pressure drops may be minimized. Fixing improperly operating filters will also prevent contaminants from entering into equipment, which can cause premature wear. Generally, when pressure drops exceed 2 psi to 3 psi, particulate and lubricant removal elements should be replaced. Regular filter cleaning and replacement has been projected to reduce compressed air system energy consumption by around 2% (Radgen and Blaustein 2001).

- *Keeping compressor motors properly lubricated and cleaned*. Poor motor cooling can increase motor temperature and winding resistance, shortening motor life and increasing energy consumption. Compressor lubricant should be changed every 2 to 18 months and periodically checked to make sure that it is at the proper level. In addition, proper compressor motor lubrication will reduce corrosion and degradation of the system.

- *Inspection of fans and water pumps* for peak performance.

- *Inspection of drain traps* to ensure that they are not stuck in either the open or closed position and are clean. Some users leave automatic condensate traps partially open at all times to allow for constant draining. This practice wastes substantial energy and should never be undertaken. Instead, simple pressure driven valves should be employed. Malfunctioning traps should be cleaned and repaired instead of left open. Some auto drains, such as float switch or electronic drains, do not waste air. Inspecting and maintaining drains typically has a payback of less than two years (U.S. DOE 2004a).

- *Maintaining the coolers* on the compressor to ensure that the dryer gets the lowest possible inlet temperature (U.S. DOE and CAC 2003).

- *Compressor belt inspection.* Where belt-driven compressors are used, belts should be checked regularly for wear and adjusted. A good rule of thumb is to adjust them after every 400 hours of operation.

- *Replacing air lubricant separators* according to specifications or sooner. Rotary screw compressors generally start with their air lubricant separators having a 2 psi to 3 psi pressure drop at full load. When the pressure drop increases to 10 psi, the separator should be changed (U.S. DOE and CAC 2003).

- *Checking water-cooling systems* regularly for water quality (pH and total dissolved solids), flow, and temperature. Water-cooling system filters and heat exchangers should be cleaned and replaced per the manufacturer's specifications.

- *Minimizing compressed air leak throughout the systems.*

- Applications requiring compressed air should be *checked for excessive pressure, duration, or volume*. Applications not requiring maximum system pressure should be regulated, either by production line sectioning or by pressure regulators on the equipment itself. Using more pressure than required wastes energy and can also result in shorter equipment life and higher maintenance costs. Case studies have demonstrated that the payback period for this measure can be shorter than half a year (IAC 2003).

Monitoring. In addition to proper maintenance, a continuous monitoring system can save significant energy and operating costs in compressed air systems. Effective monitoring systems typically include the following (CADDET 1997a):

- Pressure gauges on each receiver or main branch line and differential gauges across dryers, filters, etc.

- Temperature gauges across the compressor and its cooling system to detect fouling and blockages.

- Flow meters to measure the quantity of air used.

- Dew point temperature gauges to monitor the effectiveness of air dryers.

- Kilowatt-hour meters and hours run meters on the compressor drive.

- Checking of compressed air distribution systems after equipment has been reconfigured to be sure that no air is flowing to unused equipment or to obsolete parts of the compressed air distribution system.

- Checking for flow restrictions of any type in a system, such as an obstruction or roughness, which can unnecessarily raise system operating pressures. As a rule of thumb, every 2 psi pressure rise resulting from resistance to flow can increase compressor energy use by 1% (U.S. DOE and CAC 2003). The highest pressure drops are usually found at the points of use, including undersized or leaking hoses, tubes, disconnects, filters, regulators, valves, nozzles and lubricators (demand side), as well as air/lubricant separators, after-coolers, moisture separators, dryers and filters.

- Checking for compressed air use outside production hours.

Leak reduction. Air leaks can be a significant source of wasted energy. A typical industrial facility that has not been well maintained will likely have a leak rate ranging from 20% to 30% of total compressed air production capacity (U.S. DOE and CAC 2003). Overall, a 20% reduction of annual energy consumption in compressed air systems is projected for fixing leaks (Radgen and Blaustein 2001).

The magnitude of the energy loss associated with a leak varies with the size of the hole in the pipes or equipment. A compressor operating 2,500 hours per year at 87 psi with a leak diameter of 0.02 inches (½ mm) is estimated to lose 250 kWh per year; 0.04 inches (1 mm) to lose 1,100 kWh per year; 0.08 inches (2 mm) to lose 4,500 kWh per year; and 0.16 in. (4 mm) to lose 11,250 kWh per year (CADDET 1997a). Several industrial case studies suggest that the payback period for leak reduction efforts is generally shorter than two months (IAC 2003).

In addition to increased energy consumption, leaks can make air-powered equipment less efficient, shorten equipment life, and lead to additional maintenance costs and increased unscheduled downtime. Leaks also cause an increase in compressor energy and maintenance costs.

The most common areas for leaks are couplings, hoses, tubes, fittings, pressure regulators, open condensate traps and shut-off valves, pipe joints, disconnects, and thread sealants. The best way to detect leaks is to use an ultrasonic acoustic detector, which can recognize the high frequency hissing sounds associated with air leaks. Leak detection and repair programs should be ongoing efforts.

In 1994, Mead-Johnson Nutritionals, a manufacturer of infant formula and adult nutritional supplements, implemented a compressed air system improvement project at its plant in Evansville, Indiana. Energy efficiency measures included the introduction of a monitoring system, the installation of new compressors, and the repair of leaks. The improved compressed air system of this plant functioned so efficiently that only two-thirds of the compressed air capacity had to be kept online. The company saved $102,000 per year in compressed air system energy costs (4% of the total power costs of the plant) with a payback period of just over 2.5 years. Additionally, the project helped the plant avoid the purchase of a new ($900,000) compressor (DOE 2001d).

Turning off unnecessary compressed air. Equipment that is no longer using compressed air should have the air turned off completely. This can be done using a simple solenoid valve. Compressed air distribution systems should be checked when equipment has been reconfigured to ensure that no air is flowing to unused equipment or to obsolete parts of the compressed air distribution system.

Modification of system in lieu of increased pressure. For individual applications that require a higher pressure, instead of raising the operating pressure of the whole system, special equipment modifications should be considered, such as employing a booster, increasing a cylinder bore, changing gear ratios, or changing operation to off peak hours.

Replacement of compressed air by alternative sources. Many operations can be accomplished more economically and efficiently using energy sources other than compressed air (U.S. DOE 2004b, 2004c). Various options exist to replace compressed air use, including:

- Cooling electrical cabinets: air conditioning fans should be used instead of using compressed air vortex tubes.

- Flowing high-pressure air past an orifice to create a vacuum: a vacuum pump system should be applied instead of compressed air venturi methods.

- Cooling, aspirating, agitating, mixing, or package inflating: use blowers instead of compressed air.

- Cleaning parts or removing debris: brushes, blowers, or vacuum pump systems should be used instead of compressed air.

- Moving parts: blowers, electric actuators, or hydraulics should be used instead of compressed air.

- Tools or actuators: electric motors should be considered because they are more efficient than using compressed air (Howe and Scales 1995). However, it has been reported that motors can have less precision, shorter lives, and lack safety compared to compressed air. In these cases, using compressed air may be a better choice.

Based on numerous industrial case studies, the average payback period for replacing compressed air with other applications is estimated at 11 months (IAC 2003).

Improved load management. Because of the large amount of energy consumed by compressors, whether in full operation or not, partial load operation should be avoided. For example, unloaded rotary screw compressors still consume 15% to 35% of full-load power while delivering no useful work (U.S. DOE and CAC 2003).

Air receivers can be employed near high demand areas to provide a supply buffer to meet short-term demand spikes that can exceed normal compressor capacity. In this way, the number of required online compressors may be reduced. Multi-stage compressors theoretically operate more efficiently than single-stage compressors. Multi-stage compressors save energy by cooling the air between stages, reducing the volume and work required to compress the air. Replacing single-stage compressors with two-stage compressors typically provides a payback period of two years or less (Ingersoll-Rand 2001). Using multiple smaller compressors instead of one large compressor can save energy as well. Large compressors consume more electricity when they are unloaded than do multiple smaller compressors with similar overall capacity. An analysis of U.S. case studies shows an average payback period for optimally sizing compressors of about 1.2 years (IAC 2003).

Pressure drop minimization. An excessive pressure drop will result in poor system performance and excessive energy consumption. Flow restrictions of any type in a system, such as an obstruction or roughness, results in higher operating pressures than is truly needed. Resistance to flow increases the drive energy on positive displacement compressors by 1% of connected power for each 2 psi of differential (U.S. DOE and CAC 2003). The highest pressure drops are usually found at the points of use, including undersized or leaking hoses, tubes, disconnects, filters, regulators, valves, nozzles, and lubricators (demand side), as well as air/lubricant separators on lubricated rotary compressors and after-coolers, moisture separators, dryers, and filters (supply side).

Minimizing pressure drop requires a systems approach in design and maintenance. Air treatment components should be selected with the lowest possible pressure drop at specified maximum operating conditions and best performance. Manufacturers' recommendations for maintenance should be followed, particularly in air filtering and drying equipment, which can have damaging moisture effects like pipe corrosion. Finally, the distance the air travels through the distribution system should be minimized. Audits of industrial facilities found that the payback period is typically shorter than 3 months for this measure (IAC 2003).

Inlet air temperature reduction. If airflow is kept constant, reducing the inlet air temperature reduces the energy used by the compressor. In many plants, it is possible to reduce the inlet air temperature to the compressor by taking suction from outside the building. As a rule of thumb, each temperature reduction of 5°F (3°C) will save 1% compressor energy (CADDET 1997a; Parekh 2000). A payback period of two to five years has been reported for importing fresh air (CADDET 1997a). In addition to energy savings, compressor capacity is increased when cold air from outside is used. Industrial case studies have found an average payback period for importing outside air of less than 1.7 years (IAC 2005), but costs can vary significantly depending on facility layout.

Controls. The primary objectives of compressor control strategies are to shut off unneeded compressors and to delay bringing on additional compressors until needed. Energy savings for sophisticated compressor controls have been reported at around 12% annually (Radgen and Blaustein 2001). An excellent review of compressor controls can be found in Compressed Air Challenge® *Best Practices for Compressed Air Systems* (Second Edition) (Scales and McCulloch 2007). Common control strategies for compressed air systems include:

- *Start/stop (on/off) controls*, in which the compressor motor is turned on or off in response to the discharge pressure of the machine. Start/stop controls can be used for applications with very low duty cycles and are applicable to reciprocating or rotary screw compressors. The typical payback for start/stop controls is one to two years (CADDET 1997a).

- *Load/unload controls*, or constant speed controls, which allow the motor to run continuously but unloads the compressor when the discharge pressure is adequate. In most cases, unloaded rotary screw compressors still consume 15% to 35% of full-load power while delivering no useful work (U.S. DOE and CAC 2003). Hence, load/unload controls can be inefficient.

- *Modulating or throttling controls*, which allow the output of a compressor to be varied to meet flow requirements by closing down the inlet valve and restricting inlet air to the compressor. Throttling controls are applied to centrifugal and rotary screw compressors.

- *Single master sequencing system controls*, which take individual compressor capacities on-line and off-line in response to monitored system pressure demand and shut down any compressors running unnecessarily. System controls for multiple compressors typically offer a higher efficiency than individual compressor controls.

- *Multi-master controls*, which are the latest technology in compressed air system control. Multi-master controls are capable of handling four or more compressors and provide both individual compressor control and system regulation by means of a network of individual controllers (Martin et al. 2000). The controllers share information, allowing the system to respond more quickly and accurately to demand changes. One controller acts as the lead, regulating the whole operation. This strategy allows each compressor to function at a level that produces the most efficient overall operation. The result is a highly controlled system pressure that can be reduced close to the minimum level required (U.S. DOE and CAC 2003). According to Nadel et al. (2002), such advanced compressor controls are expected to deliver energy savings of about 3.5% where applied.

In addition to energy savings, the application of controls can sometimes eliminate the need for some existing compressors, allowing extra compressors to be sold or kept for backup. Alternatively, capacity can be expanded without the purchase of additional compressors. Reduced operating pressures will also help reduce system maintenance requirements (U.S. DOE and CAC 2003).

Properly sized pipe diameters. Increasing pipe diameters to the greatest size that is feasible and economical for a compressed air system can help to minimize pressure losses and leaks, which reduces system operating pressures and leads to energy savings. Increasing pipe diameters typically reduces compressed air system energy consumption by 3% (Radgen and Blaustein 2001). Further savings can be realized by ensuring other system components (e.g., filters, fittings, and hoses) are properly sized.

Heat recovery. As much as 90% of the electrical energy used by an industrial air compressor is converted into heat. In many cases, a heat recovery unit can recover 50% to 90% of this available thermal energy and apply it to space heating, process heating, water heating, make-up air heating, boiler make-up water preheating, and heat pump applications (Parekh 2000). It has been estimated that approximately 50,000 Btu/hour of recoverable heat is available for each 100 cfm of compressor capacity (U.S. DOE and CAC 2003). Payback periods are typically less than one year (IAC 2003).

Heat recovery for space heating is not as common with water-cooled compressors because an extra stage of heat exchange is required and the temperature of the available heat is somewhat low. However, with large water-cooled compressors, recovery efficiencies of 50% to 60% are typical (U.S. DOE and CAC 2003).

Natural gas engine-driven air compressors. Gas engine-driven air compressors can replace electric compressors with some advantages and disadvantages. Gas engine-driven compressors are more expensive and can have higher maintenance costs, but may have lower overall operating costs depending on the relative costs of electricity and gas. Variable-speed capability is standard for gas-fired compressors, offering a high efficiency over a wide range of loads. Heat can be recovered from the engine jacket and exhaust system. However, gas engine-driven compressors have some drawbacks: they need more maintenance, have a shorter useful life, and sustain a greater likelihood of downtime.

Ultra Creative Corporation, a U.S. manufacturer of specialty plastic bags, installed gas engine-driven compressors in its plant in Brooklyn, New York. The initial costs were $85,000 each for two 220 hp units and $65,000 for one 95 hp unit. The company reported savings of $9,000 in monthly utilities (averaging $108,000 annually) (Audin 1996).

Nestlé Canada found that its gas engine-driven air compressor system was a cost effective option when it was operated properly. The company's projected payback period was estimated as low as 2.6 years with a 75% efficient heat recovery system, and as high as 4.2 years without heat recovery (Audin 1996).

5.7 Pumps[16]

In the United States, pumping systems account for about 25% of the electricity used in manufacturing facilities. The pumping of coolants such as glycol or chilled water is common in pharmaceutical manufacturing facilities and is also a source of significant energy consumption. Studies have shown that over 20% of the energy consumed by pumping systems could be saved through changes to pumping equipment and/or control systems (Xenergy 1998).

It is important to note that initial costs are only a fraction of the life cycle costs of a pump system. Energy costs, and sometimes operations and maintenance costs, are much more important in the lifetime costs of a pump system. In general, for a pump system with a lifetime of 20 years, the initial capital costs of the pump and motor make up a mere 2.5% of the total costs (Best Practice Programme 1998). In contrast, energy costs make up about 95% of the lifetime costs of the pump. Maintenance costs comprise the remaining 2.5%. Hence, the initial choice of a pump system should be highly dependent on energy cost considerations rather than on initial costs.

---

[16] The U.S. DOE's Industrial Technologies Program provides a variety of resources for improving the efficiency of pumps, which can be consulted for more detailed information on many of the measures presented in this section. The U.S. DOE's *Improving Pumping System Performance: A Sourcebook for Industry* is a particularly helpful resource (U.S. DOE 2006). For a collection of tips, tools, and industrial case studies on motor and pump efficiency, visit the Industrial Technologies Program's *BestPractices* Motors, Pumps, and Fans website at: http://www1.eere.energy.gov/industry/bestpractices/systems.html.

Pumping systems consist of a pump, a drive motor, piping networks, and system controls (such as ASDs or throttles). The energy efficiency measures described below apply to all pump applications. Because pumps are part of a greater motor system, many of the measures described in Section 5.5 apply to pumping systems as well (including the "systems approach" to energy efficiency optimization). When available, case study data are provided to demonstrate the typical energy and/or cost savings associated with a given measure.

Maintenance. Inadequate maintenance can lower pump system efficiency, cause pumps to wear out more quickly, and increase costs. Better maintenance will reduce these problems and also save energy. Proper pump system maintenance includes the following (Hydraulic Institute 1994; U.S. DOE 1998):

- Replacement of worn impellers, especially in caustic or semi-solid applications.
- Bearing inspection and repair.
- Bearing lubrication replacement, on an annual or semiannual basis.
- Inspection and replacement of packing seals. Allowable leakage from packing seals is usually between 2-60 drops per minute.
- Inspection and replacement of mechanical seals. Allowable leakage is typically 1-4 drops per minute.
- Wear ring and impeller replacement. Pump efficiency degrades 1-6 points for impellers less than the maximum diameter and with increased wear ring clearances.
- Pump/motor alignment check.

Although energy savings for operations and maintenance are less than for other measures, typical savings at U.S. facilities are estimated to be between 2% and 7% of pumping electricity with paybacks of less than 1 year (Xenergy 1998; U.S. DOE 2002b).

Monitoring. Monitoring in conjunction with a proper maintenance program can be used to detect problems and determine solutions to create a more efficient pumping system. Monitoring can determine clearances that need be adjusted, indicate blockage, impeller damage, inadequate suction, operation outside preferences, clogged or gas-filled pumps or pipes, or worn out pumps. Monitoring should include the following:

- Wear monitoring.
- Vibration analyses.
- Pressure and flow monitoring.

- Current or power monitoring.
- Differential head and temperature rise across the pump (also known as thermodynamic monitoring).
- Distribution system inspection for scaling or contaminant build-up.

Pump demand reduction. Holding tanks can be used to equalize the flow over the production cycle, enhancing energy efficiency and potentially reducing the need to add pump capacity. In addition, bypass loops and other unnecessary flows should be eliminated. Each of these steps can save 5-10% of pump system electricity consumption, on average for U.S. facilities (Easton Consultants 1995). Total head requirements can also be reduced by lowering process static pressure, by minimizing the elevation rise from suction tanks to discharge tanks, by reducing static elevation changes via siphons, and by lowering spray nozzle velocities.

Controls. The objective of any control strategy is to shut off unneeded pumps or, alternatively, to reduce pump load until needed. In 2000, Cisco Systems upgraded the controls on its fountain pumps to turn off the pumps during peak hours (CEC and OIT 2002). A wireless control system was able to control all pumps simultaneously from one location. The project saved $32,000 and 400,000 kWh annually, representing a savings of 61.5% in the total energy consumption of the fountain pumps. With a total cost of $29,000, the simple payback was 11 months. In addition to energy savings, the project reduced maintenance costs and increased the pumping system's equipment life.

High-efficiency pumps. According to inventory data, 16% of pumps in use in industry are more than 20 years old. A pump's efficiency may degrade by 10-25% in its lifetime (Easton Consultants 1995). Newer pumps are typically 2-5% more efficient, while high-efficiency motors have also been shown to increase the efficiency of a pumping system by 2-5% (Tutterow 1999). More information on high-efficiency motors can be found in Section 5.5.

A number of high-efficiency pumps are available for specific pressure head and flow rate capacity requirements. Choosing the right pump often saves both operating costs and capital costs. For a given duty, selecting a pump that runs at the highest speed suitable for the application will generally result in a more efficient selection as well as the lowest initial cost (Hydraulic Institute and Europump 2001). Exceptions to this include slurry handling pumps, high specified-speed pumps, or pumps that require a very low minimum net positive suction head at the pump inlet.

Properly sized pumps. Pumps that are sized inappropriately result in unnecessary losses. Where peak loads can be reduced, pump size can also be reduced. Replacing oversized pumps with pumps that are properly sized can save 15-25% of the electricity consumption of a pumping system (on average for U.S. industry) (Easton Consultants 1995). Where pumps are dramatically oversized, speed can be reduced with gear or belt drives or a slower speed motor. Paybacks for implementing these solutions are typically less than 1 year (U.S. DOE 2002b).

As a participant in the U.S. DOE's Motor Challenge Program, the Welches Point Pump Station (a medium-sized water treatment plant located in Milford, Connecticut) replaced one of their system's four identical pumps with a smaller model (ITT Flygt 2002). They found that the smaller pump could more efficiently handle typical system flows and the remaining three larger pumps could be reserved for peak flows. While the smaller pump needed to run longer to handle the same total volume, its slower pace and reduced pressure resulted in less friction-related losses and less wear and tear. Substituting the smaller pump has resulted in savings of more than 20% of the pump system's annual electrical energy consumption. Using this system at each of the city's 36 stations would result in annual energy savings of over $100,000. In addition to the energy savings projected, less wear on the system results in less maintenance, less downtime, and longer life for the equipment. Additionally, the station noise was significantly reduced with the smaller pump.

Multiple pumps for variable loads. Often using multiple pumps is the most cost-effective and most energy efficient solution for varying loads, particularly in a static head-dominated system. Installing parallel systems for highly variable loads saves 10-50% of the electricity consumption for pumping (on average for U.S. industry) (Easton Consultants 1995). Parallel pumps also offer redundancy and increased reliability. One case study of a Finnish pulp and paper plant indicated that installing an additional small pump (a "pony pump"), running in parallel to the existing pump used to circulate water from the paper machine into two tanks, reduced the load in the larger pump in all cases except for startup. The energy savings were estimated at $36,500 per year (or 486 MWh per year) giving a payback of just 6 months (Hydraulic Institute and Europump 2001).

Impeller trimming. If a large differential pressure exists at the operating rate of flow (indicating excessive flow), the impeller diameter can be trimmed (also called "sheave shaving") so that the pump does not develop as much head. In the food processing, paper, and petrochemical industries, trimming impellers or lowering gear ratios is estimated to save as much as 75% of the electricity consumption of a given pump (Xenergy 1998).

In one case study in the chemical processing industry, a pump impeller was reduced from 320 mm to 280 mm, which reduced the pump's power demand by more than 25% (Hydraulic Institute and Europump 2001). Annual energy demand was reduced by 83 MWh (26%). With an investment cost of $390, the payback on energy savings alone was 23 days. In addition to energy savings, maintenance costs were reduced, system stability was improved, pump cavitation was reduced, and excessive vibration and noise were eliminated.

To reduce energy consumption and improve the performance of its beer cooling process, the Stroh Brewery Company analyzed the glycol circulation system used for batch cooling of beer products at its G. Heileman Division brewing facility in La Crosse, Wisconsin. By simply reducing the diameter of the pump impeller and fully opening the discharge gate valve, cooling circulation system energy use was reduced by 50%, resulting in savings of $19,000 in the first year. With a cost of $1,500, this Motor Challenge Showcase Demonstration project realized a simple payback of about 1 month (U.S. DOE 2001c).

5.8 Refrigeration

Refrigeration is another important process in the pharmaceutical industry and is used in many different applications. Energy savings in refrigeration systems can be found at the component, process, and systems levels (ATLAS Project 1997). Energy efficiency measures include reducing condenser pressures, the correct selection and sequencing of compressors, optimizing insulation, and eliminating non-essential heat loads within the plant. Additionally, many of the efficiency measures for motors, compressors, pumps, and buildings (shell) described in previous sections of this Energy Guide also apply to refrigeration systems.

Operations and maintenance. Often it is possible to achieve energy savings at very low investment costs with attention to improved operations and maintenance of refrigeration systems (Caffal 1995). Such improvements can include shutting doors, setting correct head pressure, maintaining correct levels of refrigerant, effectively maintaining cooling towers, and selecting and running appropriate compressors for part load. Energy saving can also be achieved by cleaning the condensers and evaporators. Scale on condensers increases power input and decreases refrigeration output. Three millimeters of scale can increase power input by 30% and reduce output by 20% (Kidger 2001). Water treatment and blowdown or magnetic water treatment may eliminate scales. In ammonia system evaporators, oil tends to accumulate and needs to be drained to avoid reduction of heat transfer. Additionally, cool outside air in winter months can sometimes be leveraged to reduce facility cooling energy loads (Farrell 1998).

Systems monitoring. The introduction of automatic monitoring on refrigeration systems can help energy managers and facilities engineers track energy consumption, diagnose poor performance, optimize system performance, and identify problem areas before major repairs are needed. Automated monitoring of energy performance is not yet common but can be very beneficial in exposing poor part-load efficiency and in identifying system deterioration, such as the effects of low refrigerant charge. The cost of automated monitoring is proportional to the size of the system and may be minor on new systems, where much data can often be obtained from control systems. The monitoring system should have the ability to provide system and component level information to operating staff as well as high-level performance summaries for management. It is estimated that 3% of refrigeration energy can be saved by applying this measure.

Monitoring of refrigerant charge. A low refrigerant charge can exist in many small direct expansion (DX) systems, and can also exist without obvious indicators on larger flooded or recirculation systems. Without proper monitoring to ensure that refrigerant is charged to the appropriate level, significant amounts of energy can be wasted in a refrigeration system. Scott (2004) estimates for DX systems, one in six have a low refrigerant charge (or sometimes overcharge), which is sufficient to increase energy usage by 20%. Monitoring of refrigerant charge generally isn't necessary for large ammonia systems.

Optimization of condenser and evaporator parameters. An optimized refrigeration system works with minimized differences between condenser conditions and evaporator conditions. For the condenser, the goal is to obtain the lowest possible condensing temperature and pressure of the refrigerant. This reduces power input while increasing refrigeration output. For the evaporator, an increase in temperature and pressure increases the power input of the compressor, but can dramatically increase the refrigeration output of the system. Increasing evaporator temperature by one degree can reduce the electricity consumption of the compressor by roughly 3% (Hackensellner 2001; Lom and Associates 1998).

Monitoring of suction line filters. When a suction line filter becomes clogged with debris, the pressure drop across the filter is increased, reducing the efficiency of the system. Additionally, it is important to monitor whether or not debris is being carried out with the return vapor. If so, it is likely that erosion is occurring on the internal surface of the suction pipe, which can lead to premature pipe failure. If debris is found, a corrosion-rate testing program should be implemented (Dettmers 2004).

Generally this measure applies to smaller DX systems (usually halocarbon-based systems, but not ammonia-based systems). However, all refrigeration systems can be monitored for unusual pressure drops that can originate from many sources (Scott 2004); such monitoring can lead to energy savings of approximately 3%.

Monitoring of refrigerant contamination. Periodic monitoring for contaminants (e.g., oil, water, etc.) in refrigerants should be performed to ensure early detection of system operating and maintenance problems. Energy savings due to implementation of this measure are estimated at 2%.

Cooling line and jacket insulation. It can often be cost effective to insulate cooling lines if the lines are un-insulated and there is a significant average temperature difference between the cooling lines and the surroundings (e.g., more than 15°F). If lines are already insulated, upgrading may not be cost effective. Interestingly, insulated jacket tanks use less refrigeration energy than tanks in an insulated enclosure (cold room) due to reduced losses (Kidger 2001).

Waste heat recovery. The waste heat from refrigeration systems can be recovered to provide space heating or water heating, where feasible, to reduce the electricity and/or fuel consumed by those heating demands. The technology for waste heat recovery from refrigeration systems is similar to waste heat recovery technology for compressed air compressors (see Section 5.6).

Operation at lower system pressure. High operating pressures in refrigeration systems lead to high compressor energy consumption and head loss. Lower operating pressures can reduce compressor energy consumption, while also leading to reduced system maintenance costs (e.g., for pipes). However, in lowering system operating pressures, one must also consider the optimal pressure and temperature requirements of condensers and evaporators (discussed previously in this section) to ensure maximum energy efficiency. Two case studies have shown the payback period associated with lowering operating pressures to be less than 1.5 years (IAC 2003).

Absorption chillers. Absorption chillers use heat to provide cooling, instead of mechanical energy. In absorption chillers, refrigerant vapor from the refrigeration system's evaporator is first absorbed by a solution contained in an absorber unit. Next, this solution is pumped from the absorber into a generator, which re-vaporizes the refrigerant using waste heat (e.g., from steam) as an energy source. Finally, the refrigerant-depleted solution returns to the absorber unit via a throttling device, completing the cycle. Absorption chillers have a lower coefficient of performance (COP) than mechanical chillers; however, absorption chillers can reduce operating costs since they use low-grade waste heat as an energy source. Low-pressure, steam-driven absorption chillers are available in capacities from 100 to 1,500 tons (U.S. DOE 2003). Absorption cooling and refrigeration may be attractive in combination with cogeneration of heat and power (so-called trigeneration; see Section 5.11).

5.9 Lighting

The energy used for lighting in the pharmaceutical industry is typically small. Still, energy efficiency opportunities may be found that can reduce lighting energy use cost-effectively. Lighting is used either to provide overall ambient lighting throughout manufacturing, storage, and office spaces or to provide low-bay and task lighting to specific areas. High-intensity discharge (HID) sources are used for the former, including metal halide, high-pressure sodium, and mercury vapor lamps. Fluorescent, compact fluorescent, and incandescent lights are typically used for task lighting in offices. ENERGY STAR provides more useful information on optimizing lighting in offices and buildings on its website (http://www.energystar.gov).

As with motor systems, the most effective and efficient strategy is to employ a systems approach toward meeting lighting needs. For example, the Louis Stokes Laboratories of the U.S. National Institutes of Health applied a combination of strategies to improve the efficiency of their lighting systems. First, all fluorescent light fixtures were replaced with more efficient T-8 lights and electronic ballasts. Second, motion sensor-activated lights and light emitting diode (LED) exit signs were installed. Third, a programmable lighting control system was installed. Lastly, double-height windows and curved ceilings were employed to allow more daylight into the lab space. Based on these measures, the average energy consumption rate per unit lighting area was reduced to an impressive 1.6 W per gross ft^2 (U.S. EPA/DOE 2001b).

The Process and Environmental Technology Laboratory of Sandia National Laboratories, located in Albuquerque, New Mexico, adopted similar measures as the Louis Stokes Labs. The expectation was to be able to reduce lighting levels to 1 W per ft^2, but the actual energy consumption after measure implementation was found to be 25% lower at 0.75 W per ft^2 (U.S. EPA/DOE 2001c).
Lighting also generates a significant amount of heat. The downstream savings of lighting efficiency measures can therefore include cost savings in facility HVAC operation and energy use. The magnitude of downstream savings depends on climate and weather conditions (Sezgen and Koomey 2000).

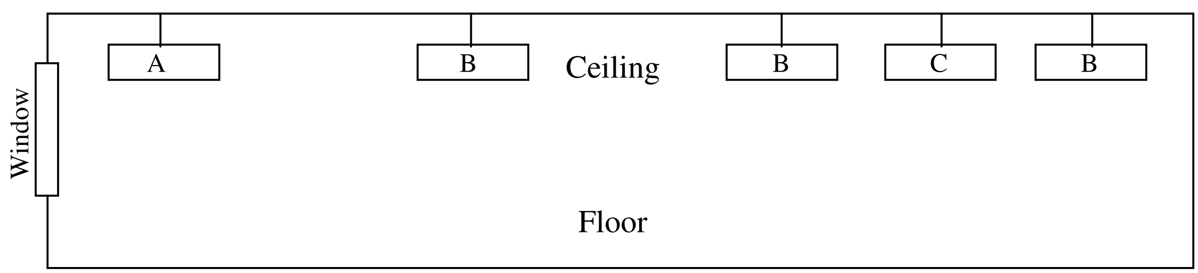
Turning off lights in unoccupied areas. An easy and effective measure is to encourage personnel to turn off lights in unoccupied building spaces. An energy management program that aims to improve the awareness of personnel with regard to energy use can help staff get in the habit of switching off lights and other equipment when not in use.

Lighting controls. Lights can be shut off during non-working hours by automatic controls, such as occupancy sensors that turn off lights when a space becomes unoccupied. Occupancy sensors can save up to 10-20% of facility lighting energy use. Numerous case studies throughout the United States suggest that the average payback period for occupancy sensors is approximately 1 year (IAC 2003).

At a Merck office and storage building in Rahway, New Jersey, lighting panels were programmed to turn off automatically during expected periods of building non-use (override switches in entrance hallways allowed lights to be turned on manually during these times, if needed). Annual savings amounted to 1,310 MBtu per year, which corresponded to avoided energy-related CO_2 emissions of nearly 260 tons per year (Merck 2005).

Manual controls can be used in conjunction with automatic controls to save additional energy in smaller areas. One of the easiest measures is to install switches to allow occupants to control lights. It is also important to make employees aware of the importance of turning off lights in unoccupied spaces (EDR 2000). Other lighting controls include daylight controls for indoor and outdoor lights, which adjust the intensity of electrical lighting based on the availability of daylight.

Figure 8. Lighting placement and controls.



An example of energy efficient lighting control is illustrated by Figure 8, which depicts five rows of overhead lights in a workspace. During the brightest part of the day, ample daylight is provided by the window and thus only row C would need to be turned on. At times when daylight levels drop, all B rows would be turned on and row C would be turned off. Only at night or on very dark days would it be necessary to have both rows A and B turned on (Cayless and Marsden 1983). These methods can also be used as a control strategy on a retrofit by adapting the luminaries already present. (For example, turning on the lighting in the rows away from the windows during the brightest parts of the day and turning on supplemental rows as needed later.)

Exit signs. Energy costs can be reduced by switching from incandescent lamps to LEDs or radium strips in exit sign lighting. An incandescent exit sign uses about 40 W, while LED signs may use only about 4-8 W, reducing electricity use by 80-90%. A 1998 Lighting

Research Center survey found that about 80% of exit signs being sold use LEDs (LRC 2001). The lifetime of an LED exit sign is about 10 years, compared to 1 year for incandescent signs, reducing maintenance costs considerably. In addition to exit signs, LEDs are increasingly being used for path marking and emergency wayfinding systems. Their long life and cool operation allows them to be embedded in plastic materials, which makes them perfect for such applications (LRC 2001).

A new LED exit sign typically costs $20-$30. Kits are sold to retrofit the lamps in existing exit signs for similar prices. The payback period can be as low as 6 months. The U.S. EPA's ENERGY STAR program website (http://www.energystar.gov) provides a list of suppliers of LED exit signs.

An alternative is the Tritium exit sign that is self-luminous and therefore does not need any power supply. The lifetime of these signs is estimated at about 10 years, while the costs can be $200/piece or more. The high capital costs make this type of sign attractive for new construction or if no power supply is available.

Electronic ballasts. A ballast is a mechanism that regulates the amount of electricity required to start a lighting fixture and maintain a steady output of light. Electronic ballasts save 12-30% power over their magnetic predecessors (Cook 1998; EPA 2001). New electronic ballasts have smooth and silent dimming capabilities, in addition to longer lives (up to 50% longer), faster run-up times, and cooler operation (Eley et al. 1993; Cook 1998). New electronic ballasts also have automatic switch-off capabilities for faulty or end-of-life lamps.

The typical energy savings associated with replacing magnetic ballasts by electronic ballasts are estimated to be roughly 25%; however, the total energy savings will depend on the number of magnetic ballasts still in use.

Replacing T-12 tubes with T-8 tubes. In many industrial facilities, it is common to find T-12 lighting tubes in use. T-12 lighting tubes are 12/8 inches in diameter (the "T-" designation refers to a tube's diameter in terms of 1/8 inch increments). T-12 tubes consume significant amounts of electricity, and also have extremely poor efficacy, lamp life, lumen depreciation, and color rendering index. Because of this, the maintenance and energy costs of T-12 tubes are high. Replacing T-12 lamps with T-8 lamps (smaller diameter) approximately doubles the efficacy of the former. Also, T-8 tubes generally last 60% longer than T-12 tubes, which leads to savings in maintenance costs. Typical energy savings from the replacement of a T-12 lamp by a T-8 lamp are around 30%. Based on experiences with several U.S. industrial facilities, the investment costs for replacing a T-12 lamp by a T-8 lamp with an electronic ballast are estimated at $0.25-$0.30/kWh-saved.

Replacing mercury lights with metal halide or high-pressure sodium lights. Where color rendition is critical, metal halide lamps can replace mercury or fluorescent lamps with energy savings of 50%. The Gillette Company manufacturing facility in Santa Monica, California, replaced 4,300 T-12 lamps with 496 metal halide lamps in addition to replacing 10 manual switches with 10 daylight switches (U.S. EPA 2001). They reduced electricity by 58% and saved $128,608 annually. The total project cost was $176,534, producing a payback period of less than 1.5 years.

Where color rendition is not critical, high-pressure sodium lamps offer energy savings of 50-60% compared to mercury lamps (Price and Ross 1989).

High-intensity discharge (HID) voltage reduction. Reducing lighting system voltage can also save energy. A Toyota plant installed reduced-voltage HID lights and realized a 30% reduction in lighting energy consumption (Toyota 2002). There are commercial products on the market that attach to a central panel switch (controllable by computer) and constrict the flow of electricity to lighting fixtures, thereby reducing voltage and saving energy, with an imperceptible loss of light. Voltage controllers work with both HID and fluorescent lighting systems and are available from multiple vendors.

High-intensity fluorescent lights. Traditional HID lighting can be replaced with high-intensity fluorescent lighting. These new systems incorporate high-efficiency fluorescent lamps, electronic ballasts, and high-efficacy fixtures that maximize output to the work plane. Advantages to the new system are many; they have lower energy consumption, lower lumen depreciation over the lifetime of the lamp, better dimming options, faster startup and re-strike capabilities, better color rendition, higher pupil lumens ratings, and less glare (Martin et al. 2000). High-intensity fluorescent systems can yield 50% electricity savings over standard metal halide HID systems. Dimming controls on high-intensity fluorescent systems that are impractical in metal halide HIDs can also save significant energy. Retrofitted systems cost about $185 per fixture, including installation costs (Martin et al. 2000).

At a Novartis plant in Rzeszow, Poland, lighting was provided by mercury lamps that offered low lighting efficiency at a high power consumption rate. The mercury lamps also did not meet Hazard Analysis and Critical Control Point (HACCP) requirements. The plant management decided to invest in a newly-designed system using highly-efficient modern fluorescent lamps within a broader framework of facility modernization plans. The result was an 85% increase in lighting intensity, a 30% reduction in power consumption, and the meeting of HACCP requirements through the special burst-safe design of the lamps (Novartis 2004).

Daylighting. Daylighting involves the efficient use of natural light in order to minimize the need for artificial lighting in buildings. Increasing levels of daylight within rooms can reduce electrical lighting loads by up to 70% (CADDET 2001; IEA 2000). Unlike conventional skylights, an efficient daylighting system may provide evenly dispersed light without creating heat gains. The reduced heat gains will reduce the need for cooling compared to skylights. Daylighting differs from other energy efficiency measures because its features are integral to the architecture of a building; therefore, it is applied primarily to new buildings and incorporated at the design stage. However, existing buildings can often be cost-effectively refitted with daylighting systems. Various daylighting systems are available on the market, some of which can be supplied as kits to retrofit an existing building.

Daylighting can be combined with lighting controls to maximize its benefits. Because of its variability, daylighting is almost always combined with artificial lighting to provide the necessary illumination on cloudy days or after dark (see also Figure 8). Daylighting technologies include properly placed and shaded windows, atria, angular or traditional (flat) roof lights, clerestories, light shelves, and light ducts. Clerestories, light shelves, and light ducts accommodate various angles of the sun and redirect daylight using walls or reflectors.

Not all parts of a facility may be suitable for the application of daylighting. Daylighting is most appropriate for those areas that are used in daytime hours by people. The savings will vary widely depending the facility and buildings. Daylighting systems typically have a payback period of around 4 years, although shorter paybacks have been achieved.

More information on daylighting can be found at the website of the Daylighting Collaborative led by the Energy Center of Wisconsin (http://www.daylighting.org/). Additionally, the Labs 21 Program has developed specific guidelines for employing daylighting in laboratory space (U.S. EPA/DOE 2000) and the International Energy Agency has published a daylighting sourcebook (IEA 2000).

At Pharmacia's Building Q, located in Skokie, Illinois, windows with Low-E glass were employed to filter out infrared rays while allowing visible light to enter the building. Two skylit atria in the building also permit more light to pour into its interior. The energy consumption of their daylighting design was anticipated to be 4.5 kWh per gross ft^2; upon implementation, energy consumption was found to be only 3.1 kWh per gross ft^2 (U.S. EPA/DOE 2002a).

5.10 Heat and Steam Distribution

Boilers are the heart of a steam system, while the purpose of distribution systems is to get steam from the boiler to the process where it will be used. Boilers and steam distribution systems are major contributors to energy losses at many industrial facilities; they are therefore an area where substantial efficiency improvements are typically feasible. Many common energy efficiency measures for boilers and steam distribution are listed below. These measures center around improved process control, reduced heat loss, and improved heat recovery. In addition to the measures below, it is important to note that new boilers should almost always be constructed in a custom configuration. Pre-designed boilers can often be out-of-date designs that cannot be tuned to the needs of a particular steam generation and distribution system (Ganapathy 1994).

Boiler process control. Flue gas monitors maintain optimum flame temperature and monitor carbon monoxide (CO), oxygen, and smoke. The oxygen content of the exhaust gas is a combination of excess air (which is deliberately introduced to improve safety or reduce emissions) and air infiltration (air leaking into the boiler). By combining an oxygen monitor with an intake airflow monitor, it is possible to detect even small leaks. A small 1% air infiltration will result in 20% higher oxygen readings. A higher CO or smoke content in the exhaust gas is a sign that there is insufficient air to complete fuel burning. Using a combination of CO and oxygen readings, it is possible to optimize the fuel/air mixture for high flame temperature (and thus the best energy efficiency) and lower air pollutant emissions. It is assumed that this measure can be applied to large boilers only because small boilers will not make up the initial capital cost as easily. Several case studies indicate that the average payback period for this measure is around 1.7 years (IAC 2003).

Reduction of flue gas quantities. Often excessive flue gas results from leaks in the boiler and/or in the flue. This reduces the heat transferred to the steam and increases pumping requirements. These leaks are often easily repaired. Savings amount to 2-5% of the energy formerly used by the boiler (U.S. DOE 2001a). This measure differs from flue gas monitoring in that it consists of a periodic repair based on visual inspection. The savings from this measure and from flue gas monitoring are not cumulative, as they both address the same losses.

Reduction of excess air. The more excess air is used to burn fuel, the more heat is wasted in heating this air rather than in producing steam. Air slightly in excess of the ideal stochiometric fuel/air ratio is required for safety and to reduce emissions of nitrogen oxides (NO_x), but approximately 15% excess air is adequate (DOE 2001d; Ganapathy 1994). The vast majority of boilers already operate at 15% excess air or lower, and thus this measure may not be widely applicable (Zeitz 1997). However, if the boiler is using excess air, numerous case studies indicate that the payback period for this measure is less than a year (IAC 2003). A rule of thumb often used is that boiler efficiency can be increased by 1% for each 15% reduction in excess air or 40°F (22°C) reduction in stack gas temperature (DOE 2001d). The Canadian Industry Program for Energy Conservation (CIPEC) estimates that reducing oxygen in flue gas by 1% increases boiler efficiency by 2.5% (CIPEC 2001).

Properly sized boiler systems. Correctly designing the boiler system at the proper steam pressure can save energy by reducing stack temperature, reducing piping radiation losses, and reducing leaks in traps and other sources. In a study done in Canada on 30 boiler plants, savings from this measure ranged from 3-8% of the total gas consumption (Griffin 2000). Savings were greatest when steam pressure is reduced below 70 psig.

Using smaller boilers when not operating at or near full load also reduces energy use. The Saskatchewan Penitentiary in Canada installed two new smaller boilers for their summer operations and to supplement winter operations. These replaced old oversized boilers operating at low fire for most of the year. They found gas savings of 17% (or 18,321 MBtu), resulting in annual energy cost savings of $50,000 (CIPEC 2001). One case study has shown that correct boiler sizing led to savings of $150,000 at a payback period of only 2.4 months (IAC 2003). Costs and savings will depend strongly on the current system utilization.

Boiler insulation. It is possible to use new materials, such as ceramic fibers, that both insulate better and have a lower heat capacity (and thus heating is more rapid). Savings of 6-26% can be achieved if improved insulation is combined with improved heater circuit controls. Due to the lower heat capacity of new materials, the output temperature of boilers can be more vulnerable to temperature fluctuations in the heating elements (Caffal 1995); improved control is therefore often required in tandem with new insulation to maintain the desired output temperature range.

Boiler maintenance. A simple maintenance program to ensure that all components of a boiler are operating at peak performance can result in substantial savings. In the absence of a good maintenance system, burners and condensate return systems can wear or get out of adjustment. These factors can end up costing a steam system up to 20-30% of initial efficiency over 2-3 years (U.S. DOE 2001d). On average, the energy savings associated with improved boiler maintenance are estimated at 10% (U.S. DOE 2001d). Improved maintenance may also reduce the emission of criteria air pollutants.

Fouling on the fireside of boiler tubes or scaling on the waterside of boilers should also be controlled. Fouling and scaling are more of a problem with coal-fed boilers than natural gas or oil-fed boilers (boilers that burn solid fuels like coal should be checked more often as they have a higher fouling tendency than liquid fuel boilers do). Tests show that a soot layer of 0.03 inches (0.8 mm) reduces heat transfer by 9.5%, while a 0.18 inch (4.5 mm) soot layer reduces heat transfer by 69% (CIPEC 2001). For scaling, 0.04 inches (1 mm) of buildup can increase fuel consumption by 2% (CIPEC 2001).

Flue gas heat recovery. According to CIPEC (2001), heat recovery from flue gas is the best opportunity for heat recovery in steam systems. Heat from flue gas can be used to preheat boiler feed water in an economizer. While this measure is fairly common in large boilers, there is often still room for more heat recovery. The limiting factor for flue gas heat recovery is that one must ensure that the economizer wall temperature does not drop below the dew point of acids contained in the flue gas (such as sulfuric acid in sulfur-containing fossil fuels). Traditionally, this has been done by keeping the flue gases exiting the economizer at a temperature significantly above the acid dew point. In fact, the economizer wall temperature is much more dependent on feed water temperature than on flue gas temperature because of the high heat transfer coefficient of water. As a result, it makes more sense to preheat feed water to close to the acid dew point before it enters the economizer. This allows the economizer to be designed so that exiting flue gas is just barely above the acid dew point. One percent of fuel use is saved for every 45°F (25°C) reduction in exhaust gas temperature (Ganapathy 1994). Case studies show an average payback period for this measure of about 2.7 years (IAC 2002). Application of this measure in the U.S. semiconductor manufacturing industry has shown a payback period as short as 11 months (Fiorino 2000).

At Merck's manufacturing facility in Elkton, Virginia, a heat recovery system was installed on two main boilers, which was used to preheat both boiler feed water and combustion feed air. The heat recovery system allowed the boiler system to approach an overall thermal efficiency of 95%. The project reduced the amount of boiler fuel by 2.85%, equivalent to 39,185 MBtu per year. Avoided CO_2 emissions amounted to nearly 2,350 tons per year (Merck 2005).

Condensate return. Reusing hot condensate in boilers saves energy, reduces the need for treated boiler feed water, and reclaims water at up to 100°C (212°F) of sensible heat. Typically, fresh feed water must be treated to remove solids that might accumulate in the boiler; however, returning condensate to a boiler can substantially reduce the amount of purchased chemical required to accomplish this treatment. The fact that this measure can save substantial energy costs and purchased chemicals costs often makes building a return piping system attractive. For example, a metal fabrication plant in the United States installed a condensate return system with an initial implementation cost of $2,800 and realized annual savings of $1,790 with a payback period of only 1.6 years (Kirk and Looby 1996).

A Pfizer plant in Groton, Connecticut, upgraded their condensate recovery system and realized a 9% reduction in electricity consumption, and an 8% reduction in water consumption and wastewater discharge (Pfizer 2001). As a result, Pfizer saved roughly $175,000 per year through avoided oil, gas, and water purchases.

Blowdown steam recovery. When water is blown from a high-pressure boiler tank, the pressure reduction often produces substantial amounts of steam. This steam is low grade, but can be used for space heating and feed water preheating. The recovery of blowdown steam can save 1.3% of boiler fuel use in small boilers[17]. Applications in the U.S. semiconductor manufacturing industry have shown payback periods of as little as 1.5 years (Fiorino 2000). Two other audits showed payback periods of 0.8 years and 2.5 years for this measure (IAC 2003), demonstrating the importance of assessing the local conditions for a proper evaluation. In addition to energy savings, blowdown steam recovery may reduce the potential for corrosion damage in steam system piping.

Boiler replacement. Replacing inefficient coal-fired boilers with gas-fired boilers increases energy efficiency and reduces emissions. Bristol Aerospace in the United Kingdom replaced two outdated boilers with three higher efficiency dual-fired natural gas/electric boilers and realized annual energy savings of $23,000 (Caffal 1995).

Distribution system insulation. Using more insulating material or using the best insulation material for the application can save energy in steam systems. Crucial factors in choosing insulating material include low thermal conductivity, dimensional stability under temperature change, resistance to water absorption, and resistance to combustion. Other characteristics of insulating material may also be important depending on the application. These characteristics include tolerance of large temperature variations, tolerance of system vibrations, and adequate compressive strength where insulation is load bearing (Baen and Barth 1994). Improving the insulation on the existing U.S. stock of heat distribution systems would save an average of 3-13% in all systems (U.S. DOE 2001d). Two case studies indicate that the payback period for improved insulation is about 1 year (IAC 2003). The Canadian Industry Program for Energy Conservation (2001a) estimates that the investment for insulating a 10 foot (3 m) long, 4 inch (10 cm) diameter steam pipe can be paid back in less than 6 months.

It is often found that after heat distribution systems have undergone some form of repair, the insulation is not replaced. In addition, some types of insulation can become brittle or rot over time. As a result, a regular inspection and maintenance system for insulation can save energy (Zeitz 1997). Exact energy savings and payback periods are unknown and vary based on the existing practices.

---

[17] Based on the following assumptions: 10% of boiler water is blown down (DOE 2001d) and 13% of the thermal energy in blowdown water can be recovered (Johnston 1995).

Steam trap improvement. Using modern thermostatic element steam traps can reduce energy use while improving reliability. The main efficiency advantages offered by these traps are that they open when the temperature is very close to that of saturated steam (within 4°F or 2°C), purge non-condensable gases after each opening, and are open on startup to allow a fast steam system warm-up. These traps also have the advantage of being highly reliable and useable for a wide variety of steam pressures (Alesson 1995).

Steam trap maintenance. A simple program of checking steam traps to ensure that they are operating properly can save significant amounts of energy for very little money. When steam traps are not regularly monitored, up to 15-20% of traps can be malfunctioning. Energy savings for a regular system of steam trap checks and follow-up maintenance is conservatively estimated at 10% (U.S. DOE 2001d; Jones 1997; Bloss et al. 1997). One case study indicates a payback period of less than 4 months (IAC 2003). Although this measure offers a quick payback period, it is often not implemented because maintenance and energy costs are separately budgeted. In addition to energy and cost savings, proper functioning of steam traps will reduce the risk of corrosion in the steam distribution system.

Steam trap monitoring. Attaching automated monitors to steam traps in conjunction with a maintenance program can save even more energy without significant added cost. This system is an improvement over steam trap maintenance alone, because it gives quicker notice of steam trap failure, and can detect when a steam trap is not performing at peak efficiency. Using automatic monitoring is conservatively estimated to give an additional 5% energy savings over steam trap maintenance alone with a payback period of 1 year[18] (Johnston 1995; Jones 1997). Systems that are able to implement steam trap maintenance are also likely to be able to implement automatic monitoring.

Leak repair. As with steam traps, the distribution pipes themselves often have leaks that (on average) go unnoticed without a program of regular inspection and maintenance. In addition to saving 3% of energy costs, having such a program can reduce the likelihood of having to repair major leaks, thus saving even more in the long term (U.S. DOE 2001d). One case study in the IAC database shows a payback period shorter than a week (IAC 2003).

Flash steam recovery. When a steam trap purges condensate from a pressurized steam distribution system to ambient pressure, flash steam is produced. As with flash steam produced by boiler blowdown, this steam can be used for space heating or feed water preheating (Johnston 1995). The potential for this measure is extremely site dependent, as it is unlikely that a producer would build an entirely new system of pipes to transport this low-grade steam to places where it can be used. If, on the other hand, the areas where low-grade heat is useful were already very close to the steam traps, this measure would be easy to implement and could save considerable energy.

Preventive maintenance. A general preventive maintenance (PM) program institutionalizes ongoing steam system checks, repairs, and upgrades to keep steam distribution systems operating at peak efficiency. General PM programs for steam distribution systems would

---

[18] Calculated based on a UK payback of 0.75 years. The U.S. payback is longer because energy prices in the U.S. are lower, while capital costs are similar.

incorporate many of the measures described above and typically lead to significant savings. For example, at Velsicol Chemical Company's Chestertown, Maryland, facility, an improved PM program was implemented to continuously identify energy losses in its steam system. The cost to implement this PM program was $22,000. This measure reduced the plant's energy consumption on a per production unit basis by 28% and had a payback of just over 2.5 months. The plant received a 1997 Chemical Manufacturers Association Energy Efficiency Award for the project (U.S. DOE 2000).

Process integration and pinch analysis. Process integration refers to the exploitation of potential synergies that are inherent in any system that consists of multiple components working together. In plants that have multiple heating and cooling demands, the use of process integration techniques may significantly improve plant energy efficiency. Developed in the early 1970s, it is now an established methodology for continuous processes (Linnhoff et al. 1992; CADDET 1993). The methodology involves the linking of hot and cold streams in a process in a thermodynamic optimal way. Process integration is the art of ensuring that the components are well suited and matched in terms of size, function, and capability.

Pinch analysis takes a systematic approach to identifying and correcting the performance limiting constraint (or pinch) in any manufacturing process. It was developed originally in the late 1970s (Linnhoff 1993) in response to the "energy crisis" and the need to reduce steam and fuel consumption in oil refineries and chemical plants by optimizing the design of heat exchanger networks. Since then, the pinch analysis approach has been extended to resource conservation in general, whether the resource is capital, time, labor, electrical power, water, or a specific chemical species such as hydrogen.

The critical innovation in applying pinch analysis was the development of "composite curves" for heating and cooling, which represent the overall thermal energy demand and availability profiles for the process as a whole. When these two curves are drawn on a temperature-enthalpy graph, they reveal the location of the process pinch (the point of closest temperature approach), and the minimum thermodynamic heating and cooling requirements. These are called the energy targets. The methodology involves first identifying the targets and then following a systematic procedure for designing heat exchanger networks to achieve these targets. The optimum approach temperature at the pinch is determined by balancing the capital-energy tradeoffs to achieve the desired payback. The procedure applies equally well to new designs and retrofits of existing plants.

The analytical approach to this analysis has been well documented in the literature (Kumana 2000; Smith 1995; Shenoy 1994). Energy savings potential using pinch analysis far exceeds that from well-known conventional techniques such as heat recovery from boiler flue gas, insulation, and steam trap management.

Pinch analysis, and competing process integration tools, have been developed further in recent years. The most important developments in the energy area are the inclusion of alternative heat recovery processes such as heat pumps and heat transformers, as well as the development of pinch analysis for batch processes (or in other words bringing in time as a factor in the analysis of heat integration). The use of process integration techniques for batch processes is especially important to the pharmaceutical industry, with its dominant use of batch processes.

Furthermore, pinch analysis should be used in the design of new processes and plants, as process integration goes beyond optimization of heat exchanger networks (Hallale 2001). Even in new designs, additional opportunities for energy efficiency improvement can be identified. Pinch analysis has also been extended to the areas of water recovery and efficiency, and hydrogen recovery.

5.11 Cogeneration

For industries like pharmaceutical manufacturing that have requirements for process heat, steam, and electricity, the use of combined heat and power (CHP) systems may be able to save energy and reduce pollution. Cogeneration plants are significantly more efficient than standard power plants because they take advantage of waste heat. In addition, transmission losses are minimized when CHP systems are located at or near the plant. As Chapter 4 showed, the use of cogeneration in the U.S. pharmaceutical industry is still limited, allowing for expansion at suitable locations.

Often, utility companies will work with individual companies to develop CHP systems for their plants. In this scenario, the utility company owns and operates the plant's CHP system; therefore, the company avoids the capital expenditures associated with CHP projects, but gains the benefits of a more energy efficient source of heat and electricity.

In addition to energy savings, CHP systems also have comparable or better availability of service than utility generation. In the automobile industry, for example, typical CHP units are reported to function successfully for 95-98% of planned operating hours (Price and Ross 1989). For installations where initial investment is large, potential multiple small-scale CHP units distributed to points of need could be used cost effectively.

Currently, most large-scale CHP systems use steam turbines. Switching to natural gas-based systems will improve the power output and efficiency of the CHP system, due to increased power production capability. Although the overall system efficiency of a steam turbine-based CHP system (80%, HHV) is higher than that of a gas turbine-based CHP system (74%, HHV), the electrical efficiency of a gas turbine-based CHP system is much higher (27-37% for typical industrial scale gas turbines) (Energy Nexus Group 2002a, 2002b). The power-to-heat ratio of a steam turbine-based CHP system is very low (limited to about 0.2), limiting the output of electricity. The power-to-heat ratio of a gas turbine-based CHP system is much higher (between 0.5 and 1.0), producing more power for the same amount of fuel. This may improve the profitability of a gas-based CHP unit, depending on the price of power to the plant. Modern gas-based CHP systems have low maintenance costs and will reduce emissions of NO_x, sulfur dioxide, CO_2, and particulate matter from power generation considerably, especially when replacing a coal-fired boiler (Energy Nexus Group 2002a, 2002b).

In general, the energy savings of replacing a traditional system (i.e., a system using boiler-based steam and grid-based electricity) with a standard gas turbine-based CHP unit is estimated at 20%-30%. The efficiency gain will be higher when replacing older or less maintained boilers.

Combined cycles (combining a gas turbine and a back-pressure steam turbine) offer flexibility for power and steam production at larger sites, and potentially at smaller sites as well. Steam-injected gas turbines (STIG) can absorb excess steam (e.g., due to seasonal reduced heating needs) to boost power production by injecting steam into the turbine. The size of typical STIGs starts around 5 MW. STIGs are found in various industries and applications, especially in Japan and Europe, as well as in the United States. For example, International Power Technology installed STIGs at Sunkist Growers in Ontario, California, in 1985. This type of turbine uses the exhaust heat from a combustion turbine to turn water into high-pressure steam. This steam is then fed back into the combustion chamber to mix with the combustion gas. The advantages of this system are (Willis and Scott 2000):

- The added mass flow of steam through the turbine increases power by about 33%.
- The machinery involved is simplified by eliminating the additional turbine and equipment used in combined cycle gas turbine.
- The steam is cool compared to combustion gases helping to cool the turbine interior.
- The system reaches full output more quickly than combined-cycle unit (30 minutes versus 120 minutes).

Additional advantages are that the amounts of power and thermal energy produced by the turbine can be adjusted to meet current power and thermal energy (steam) loads. If steam loads are reduced, the steam can then be used for power generation, increasing output and efficiency (Ganapathy 1994). Drawbacks include the additional complexity of the turbine's design. Additional attention to the details of the turbine's design and materials are needed during the design phase. This may result in a higher capital cost for the turbine compared to traditional models.

The economics of a cogeneration system depend strongly on the local situation, including power demand, heat demand, power purchasing and selling prices, natural gas prices, as well as interconnection standards and charges, and utility charges for backup power (backup charges). In some states, programs may offer support for installation of cogeneration/trigeneration systems (see also Appendix C).

Trigeneration. Furthermore, new CHP systems offer the option of trigeneration, which provides cooling in addition to electricity and heat. Cooling can be provided using either absorption or adsorption technologies, which both operate using recovered heat from the cogeneration process.

Absorption cooling systems take advantage of the fact that ammonia is extremely soluble in cold water and much less so in hot water. Thus, if a water-ammonia solution is heated, it expels its ammonia. In the first stage of the absorption process, a water-ammonia solution is exposed to waste heat from the cogeneration process, whereby ammonia gas is expelled. After dissipating the heat, the ammonia gas—still under high pressure—liquefies. The liquid ammonia flows into a section of the absorption unit where it comes into contact with hydrogen gas. The hydrogen gas absorbs the ammonia gas with a cooling effect. The hydrogen-ammonia mixture then meets a surface of cold water, which absorbs the ammonia again, closing the cycle. Absorption coolers are produced by a number of suppliers (e.g., Carrier, York, Trane, Robur, McQuay, LG Machinery, and Century).

In contrast, adsorption cooling utilizes the capacity of certain substances to adsorb water on their surface, from where it can be separated again with the application of heat. Adsorption units use hot water from the cogeneration unit. These systems do not use ammonia or corrosive salts, but use silica gel (which also helps to reduce maintenance costs). Adsorption units were originally developed in Japan and are now also marketed in the United States.

The thermal performance of absorption and adsorption systems is similar, with a COP between 0.68 and 0.75. The capital costs of both systems are also comparable. However, the reliability of an adsorption unit is expected to be better and maintenance cost is expected to be lower.

In March 2004, Johnson & Johnson Pharmaceutical Research & Development officially dedicated the installation and operation of a new CHP trigeneration system, as part of a major R&D expansion at its La Jolla, California, facility. The 2,200 kW system will produce 15 GWh per year of electricity plus 360,000 therms of heat and 1.6 million ton-hr per year of chilled water. This will provide more than 90% of the facility's electric power and much of its heating and cooling needs. This CHP system also allows the R&D facility to fully operate independent of the State of California's electrical grid, if necessary. Furthermore, emission of greenhouse gases will be reduced by more than 3 million pounds of CO_2 per year. Plus, savings in electricity and natural gas will be over $1 million per year. The San Diego Regional Energy Office helped fund the project (SDREO 2004).

Power recovery turbines. Steam is often generated at high pressures (typically at 120-150 psig), but often the pressure is reduced (to as low as 10-15 psig) to allow the steam to be used by different process. Typically, pressure reduction is accomplished through a pressure reduction valve, which does not recover the energy embodied in the pressure drop. This energy could be recovered by using a micro scale-back pressure steam turbine, which is produced by several manufacturers. Applications of this technology have been commercially demonstrated for campus facilities and in the pulp & paper, food, and lumber industries. Power recovery turbines are capable of producing 13.5 kWh/MBtu steam (Casten and O'Brien 2003). The actual power generation on a particular site will vary depending on steam pressures and steam uses.

5.12 Miscellaneous Measures

Additional energy efficiency measures, which may be applicable to areas of a pharmaceutical plant not previously discussed, are presented below.

Stand-by power. Many process instruments operate continuously even when there is no demand, for example, diagnostic instruments, measuring devices, and laboratory computers. Putting such devices into stand-by mode when unused (or turning them off, where appropriate) can reduce a plant's overall energy load. In addition to the instruments in manufacturing and R&D facilities, computers, monitors, printers, copiers, and other electronic equipment in office environments should be set to enter stand-by mode during intermittent periods of non-use and should be turned off during extended periods of non-use (e.g., nights and weekends). A recent study suggests that only a small percentage of office electronics have power-saving features enabled and that many devices are left on unnecessarily overnight (Roberson et al. 2004), which can lead to significant energy losses in an office environment.

Energy efficient office equipment. When replacing or purchasing office equipment, consider purchasing only the most energy efficient models, such as those products that have earned the ENERGY STAR. ENERGY STAR qualified office products include computers, copiers, external power adapters, fax machines, mailing machines, monitors, printers, scanners, vending machines, and water coolers. Overall, ENERGY STAR qualified office products use about half as much electricity as standard equipment, which can lead to significant savings in energy across an organization. See the ENERGY STAR website for a list of ENERGY STAR qualified office products (http://www.energystar.gov/) as well as information on a host of other energy efficient appliances.

Membranes. Membranes selectively separate one or more materials from a liquid or a gas and can replace energy-intensive separation processes. Membranes can be made from organic or inorganic materials, or can be a hybrid of both. Organic membranes can be used for processes with temperatures below 150°C. Inorganic membranes can be used in higher temperature environments, ranging from 500-800ºC using metal membranes to over 1,000ºC for many ceramic membranes. Hybrid membranes have organic molecules to allow water and dissolved substances to be filtered by the membrane and inorganic molecules to provide stability.

Membranes can be used in a wide variety of applications where separation is required (Srikanth 2004). A typical use of membranes is for water and wastewater treatment. For water treatment, the application of membranes for ultra-filtration and hyper-filtration reduces the number of steps necessary for water purification. This results in reduced maintenance and operation costs, while reducing electricity consumption. Ultra-low pressure thin-film-composite membranes need 50% less energy than cellulose acetate ones to operate (CADDET 2000).

Wastewater from the pharmaceutical industry may contain different contaminants, including bio-organic compounds and organic pollutants. Such wastewater needs to be cleaned before it can be discharged or recovered for re-use in the plant. Traditional wastewater treatment methods include the use of chemicals (coagulants) to remove impurities, flocculation, sedimentation, and fine particle (e.g. sand) filtration. The costs and energy use of wastewater treatment depends heavily on the facility, differences in flow, the type of pollutants, as well as the type of equipment used. The main driver for membrane application is the cost of wastewater treatment, and not energy use, although membranes can reduce energy use when compared to evaporation. Life-cycle costs of new, relatively small water treatment facilities (less than 20,000 m^3/day) using pressure-driven membrane processes should be less or comparable to those of new facilities using conventional processes for particle removal or reduction of dissolved organic materials (Wiesner and Chellam 1999). A recent study estimated that membrane technologies for wastewater treatment average about $30,000 in capital costs and save $6,400 annually in operating costs, resulting in a simple payback period of just under 5 years and an internal rate of return of about 20% (Martin et al. 2000). In a number of applications, the annual operating cost savings from reductions in wastewater-related fees and associated labor costs lead to simple payback periods of 3 years or less (Nini and Gimenez-Mitsotakis 1994; Pollution Engineering 2002).

It is difficult to estimate the potential energy savings from implementation of membranes for water treatment without a detailed study of the specific situation. For specific applications, energy savings may be up to 40-55% of the energy needs for evaporation. Additional production savings are often achieved through product quality, reduced water use, and lower operation costs, which are site-specific.

6. Summary and Conclusions

Pharmaceutical manufacturing consumes a considerable amount of energy. In 2002, the U.S. pharmaceutical industry spent over $900 million on energy, making energy a significant cost driver for the industry. Energy efficiency improvement is an important way to reduce these costs and to increase predictable earnings, especially in times of high energy price volatility.

Significant potential exists for energy efficiency improvement in the U.S. pharmaceutical industry. A focused and strategic energy management program will help to identify and implement energy efficiency measures and practices across an organization. Many companies in the U.S. pharmaceutical industry have already accepted the challenge to improve their energy efficiency due to steadily-rising energy prices; these companies have also begun to reap the rewards of energy efficiency investments.

There are a variety of opportunities available at individual plants in the U.S. pharmaceutical industry to reduce energy consumption in a cost-effective manner. This Energy Guide has identified many energy efficiency practices and energy efficient technologies that can be implemented at the component, process, system, and organizational levels. Expected savings in energy and energy-related costs have been provided for many energy efficiency measures, based on case study data from real-world industrial applications. Additionally, typical payback periods and references to further information in the technical literature have been provided, when available.

Table 5 summarizes the energy efficiency measures presented in this Energy Guide. While the expected savings associated with some of the individual measures in Table 5 may be relatively small, the cumulative effect of these measures across an entire plant may potentially be quite large. Additionally, the majority of the measures in Table 5 have relatively short payback periods. The degree of implementation of these measures will vary by plant and end use; continuous evaluation of these measures will help to identify further cost savings in ongoing energy management programs.

For all energy efficiency measures presented in this Energy Guide, individual plants should pursue further research on the economics of the measures, as well as on the applicability of different measures to their own unique production practices, in order to assess the feasibility of measure implementation.

Table 5. Summary of energy efficiency measures for the U.S. pharmaceutical industry.

General	
Energy management programs	Energy monitoring systems
HVAC Systems	
Energy efficient system design	Recommissioning
Energy monitoring and control systems	Non-production hours set-back temperatures
Duct leakage repair	Discharge air temperature management
Variable-air-volume systems	Adjustable speed drives
Heat recovery systems	Chiller efficiency improvement
Fan modification	Efficient exhaust fans
Cooling water recovery	Solar air heating
Building reflection	Building insulation
Low-emittance windows	
Fume Hoods	
Improved storage/housekeeping	Restriction of sash openings
Vortex promotion	Variable-air-volume hoods
Berkeley Hood	
Cleanrooms	
Reduced recirculation air change rates	Improved filtration quality and efficiency
Optimized chilled water systems	Cooling towers
Reduction of cleanroom exhaust	Declassification
Motors	
Motor management plan	Strategic motor selection
Maintenance	Properly sized motors
Adjustable-speed drives	Power factor correction
Minimizing voltage unbalances	Replacement of belt drives
Compressed Air Systems	
System improvements	Improved load management
Maintenance	Pressure drop minimization
Monitoring	Inlet air temperature reduction
Leak reduction	Controls
Turning off unnecessary compressed air	Properly sized pipe diameters
Modification of system	Heat recovery
Replacement of compressed air by other sources	Natural gas engine-driven compressors
Pumps	
Maintenance	Monitoring
Pump demand reduction	Controls
High-efficiency pumps	Properly sized pumps
Multiple pumps for variable loads	Impeller trimming
Refrigeration	
Operations and maintenance	Systems monitoring
Monitoring of refrigerant charge	Optimization of operating parameters
Monitoring of suction line filters	Monitoring of refrigerant contamination
Cooling line and jacket insulation	Waste heat recovery
Operation at lower system pressure	Absorption chillers

Table 5. (continued)

Lighting	
Turning off lights in unoccupied areas	Lighting controls
Exit signs	Electronic ballasts
Replacing T-12 lamps with T-8 lamps	Replacing mercury lights
High-intensity discharge voltage reduction	High-intensity fluorescent lights
Daylighting	
Heat and Steam Distribution	
Boiler process control	Reduction of flue gas quantities
Reduction of excess air	Properly sized boiler systems
Boiler insulation	Boiler maintenance
Flue gas heat recovery	Condensate return
Blowdown steam recovery	Boiler replacement
Distribution system insulation	Steam trap improvement
Steam trap maintenance	Steam trap monitoring
Leak repair	Flash steam recovery
Preventive maintenance	Process integration and pinch analysis
Cogeneration	
Combined heat and power	Trigeneration
Power recovery turbines	
Miscellaneous Measures	
Stand-by power	Energy efficient office equipment
Membranes	

7. Acknowledgements

This work was supported by the Climate Protection Partnerships Division of the U.S. Environmental Protection Agency as part of its ENERGY STAR program through the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

Many people inside and outside the pharmaceutical industry provided valuable insights in the preparation of this Energy Guide. The authors would like to thank the following people for their helpful comments and advice: Steve Schultz of 3M, Bret Steele of Aventis Pharmaceuticals, John Malinowski of Baldor Electric Company, Karen Hedlund and Ron Roberts of Bayer Healthcare, Ted Jones and Ilene Mason of the Consortium for Energy Efficiency, Linda Raynes of the Electrical Apparatus Service Association, Diane Colson of Eli Lilly and Company, Christian Berry of GlaxoSmithKline, Don Hertkorn of ICF Consulting, Austin H. Bonnett (IEEE Fellow), Paul Mathew, Evan Mills, Dale Sartor, and Bill Tschudi of Lawrence Berkeley National Laboratory, Vincent Gates and Helene Ferm of Merck and Company, Henry Molise of Pfizer, Peter Sibilski of Shering-Plough, and Walt Tunnessen of the U.S. Environmental Protection Agency.

Any remaining errors in this Energy Guide are the responsibility of the authors. The views expressed in this Energy Guide do not necessarily reflect those of the U.S. Environmental Protection Agency, the U.S. Department of Energy, or the U.S. Government.

8. References

Alesson, T. (1995). All Steam Traps are not Equal. Hydrocarbon Processing. Gulf Publishing Company, Houston, Texas.

ATLAS Project. (1997). Refrigeration – Future Potential. Brussels, Belgium.
http://europa.eu.int/comm/energy_transport/atlas/htmlu/refdfut.html

Audin, L. (1996). Natural Gas Engine-Driven Air Compressors, New Money-Saving Option Requires Careful Analysis. E-Source Tech Update. July.

Baen, P. R. and R. E. Barth. (1994). Insulate Heat Tracing Systems Correctly. Chemical Engineering Progress. September: 41-46.

Barnish, T. J., M. R. Muller, and D. J. Kasten. (1997). Motor Maintenance: A Survey of Techniques and Results. Proceedings of the 1997 ACEEE Summer Study on Energy Efficiency in Industry. American Council for an Energy-Efficient Economy, Washington, D.C.

Bell, G., D. Sartor, and E. Mills (2003). The Berkeley Hood: Development and Commercialization of an Innovative High-Performance Laboratory Fume Hood. Lawrence Berkeley National Laboratory, Berkeley, California. Report # LBNL-48983 (rev.)

Best Practice Programme. (1998). Distributed Small-scale CHP on a Large Manufacturing Site, Land Rover. The UK Department of the Environment, Transport and the Regions' Energy Efficiency. Good Practice Case Study 363.

Bloss, D., R. Bockwinkel and N. Rivers. (1997). Capturing Energy Savings with Steam Traps. Proceedings of the 1997 ACEEE Summer Study on Energy Efficiency in Industry. American Council for an Energy-Efficient Economy, Washington, D.C.

Caffal, C. (1995). Energy Management in Industry. Centre for the Analysis and Dissemination of Demonstrated Energy Technologies (CADDET), The Netherlands. Analyses series 17, December.

California Energy Commission (CEC). (2001). 2001 Energy Efficiency Standards for Residential and Nonresidential Buildings. California Energy Commission, Sacramento, California. P400-01-024.
http://www.energy.ca.gov/title24/2001standards/2001-10-04_400-01-024.PDF

California Energy Commission (CEC) and the Office of Industrial Technologies (OIT), Energy Efficiency and Renewable Energy, U. S. Department of Energy. (2002). Case Study: Pump System Controls Upgrade Saves Energy at a Network Equipment Manufacturing Company's Corporate Campus. January.

California Institute of Energy Efficiency (CIEE). (2000a). Cleanroom Case Study: Genentech, Vacaville: New Energy Efficient Site. Oakland, California.

California Institute of Energy Efficiency (CIEE). (2000b). Cleanroom Case Study: Hine Design: Variable Speed Drive Control on Recirculation Fans for Class 100 Cleanroom. Oakland, California.

California Institute of Energy Efficiency (CIEE). (2000c). Cleanroom Case Study: Motorola: Cleanroom Declassification from Class 10,000 to Class 100,000. Oakland, California.

Camfil AB. (1997). Hi-Flo's Prizeworthy Performance. Camfil AirMail. #2/97.

Canadian Industry Program for Energy Conservation (CIPEC). (2001a). Boilers and Heaters, Improving Energy Efficiency. Natural Resources Canada, Office of Energy Efficiency. August.

Carrier Aeroseal, LLC. (2002). Case Studies: West Coast - Single Story, Commercial. Indianapolis, Indiana. http://www.aeroseal.com/hmcis_west_01.html

Castellow, C., C. E. Bonnyman, H. G. Peach, J. C. Ghislain, P. A. Noel, M. A. Kurtz, J. Malinowski, and M. Kushler. (1997). Energy Efficiency in Automotive and Steel Plants. Proceedings of the 1997 ECEEE Summer Study, Stockholm, Sweden.

Casten, S. and T. O'Brien. (2003). Free Electricity from Steam Turbine-Generators: A System-Level Economic Analysis. Direct Energy. First Quarter: 1-3.

Cayless, M. A. and A. M. Marsden (Eds.). (1983). Lamps and Lighting. Edward Arnold, London.

Centre for the Analysis and Dissemination of Demonstrated Energy Technologies (CADDET). (1993). Proceedings IEA Workshop on Process Integration, International Experiences and Future Opportunities, Sittard, The Netherlands.

Centre for the Analysis and Dissemination of Demonstrated Energy Technologies (CADDET). (1994). High Efficiency motors for Fans and Pumps. Case study UK94.502/2B.FO5.

Centre for the Analysis and Dissemination of Demonstrated Energy Technologies (CADDET). (1996). Refrigeration Fault Diagnosis System. Case Study UK-94-565.

Centre for the Analysis and Dissemination of Demonstrated Energy Technologies (CADDET). (1997a). Saving Energy with Efficient Compressed Air Systems. Maxi Brochure 06.

Centre for the Analysis and Dissemination of Demonstrated Energy Technologies (CADDET). (1997b). Energy Savings with New Industrial Paint Drying and Baking Oven. Case study CA97.504/2X.F06.

Centre for the Analysis and Dissemination of Demonstrated Energy Technologies (CADDET). (1999). Air Purification in Gene Laboratories. Newsletter No. 2.

Centre for the Analysis and Dissemination of Demonstrated Energy Technologies (CADDET). (2000). Membrane Filtration in A Water Purification Plant. Special Issue on Netherlands.

Centre for the Analysis and Dissemination of Demonstrated Energy Technologies (CADDET). (2001). Saving Energy with Daylighting Systems. Maxi Brochure 14.

Centre for the Analysis and Dissemination of Demonstrated Energy Technologies (CADDET). (2003). A Refrigeration Plant within a Brewery Efficiently Storing Cold Heat and Recovering Waste Heat from its Refrigeration Machines. Case Study JP-2003-013.

Center for Renewable Energy and Sustainable Technology (CREST). (2001). Solar Thermal Catalog—Chapter 5.2: Ford Motor Company/ Chicago Stamping Plant. Renewable Energy Policy Project (REPP), Washington, D.C. http://solstice.crest.org/renewables/seia_slrthrm/52.html

CIPCO Energy Library (CEL). (2002). Motors and Drivers - Rewinding motors. APOGEE Interactive, Inc. http://cipco.apogee.net/mnd/merrovr.asp

Cole, G. C. (1998). Pharmaceutical Production Facilities: Design and Applications. 2nd Edition. Taylor & Francis, New York, New York.

Compressed Air Challenge (CAC). (2002). Guidelines for Selecting a Compressed Air System Service Provider and Levels of Analysis of Compressed Air Systems. http://www.compressedairchallenge.org.

Consortium for Energy Efficiency (CEE) (2007). Energy-Efficiency Incentive Programs: Premium-Efficiency Motor & Adjustable Speed Drives in the U.S. and Canada. Boston, Massachusetts. May.

Cook, B. 1998. High-efficiency Lighting in Industry and Commercial Buildings. Power Engineering Journal. October: 197-206.

Copper Development Association (CDA). (2000). Cummins engine company saves $200,000 per Year with Energy-Efficient Motors. New York, New York. Case Study A6046.

Copper Development Association (CDA). (2001). High-Efficiency Copper-Wound Motors Mean Energy and Dollar Savings. New York, New York.

Copper Development Association (CDA). (2003). Energy Efficiency Case Study: Brass Mill Cuts Costs with NEMA Premium® Motors. New York, New York. http://www.copper.org/applications/electrical/energy/Brass_Mill_Cuts_Cost_A6089.html

CREST. (2001). Solar Thermal Catalog—Chapter 5.2: Ford Motor Company/ Chicago Stamping Plant. http://solstice.crest.org/renewables/seia_slrthrm/52.html

Dome-Tech Group. (2005a). Pfizer Retro-Commissioning. Edison, New Jersey. http://www.dome-tech.com/projects/pfizer.asp

Dome-Tech Group. (2005b). Retro-Commissioning, Ethicon, Somerville, NJ. Edison, New Jersey. http://www.dome-tech.com/projects/pfizer.asp

Dunn, R.F. and G.E. Bush. (2001). Using Process Integration Technology for CLEANER Production. Journal of Cleaner Production. (9): 1-23.

Easton Consultants, Inc. (1995). Strategies to Promote Energy-Efficient Motor Systems in North America's OEM Markets. Stamford, CT.

Efficiency Partnership. (2004). Industrial Product Guide – Manufacturing and Processing Equipment: Compressed Air Equipment. Flex Your Power, San Francisco, California.

Electric Apparatus Service Association (EASA) (2003). The Effect of Repair/Rewinding on Motor Efficiency. St. Louis, Missouri.

Electric Apparatus Service Association (EASA) (2006). ANSI/EASA Standard AR100-2006. Recommended Practice for the Repair of Rotating Electrical Apparatus. St. Louis, Missouri.

Eley, C., T. M. Tolen, J. R. Benya, F. Rubinstein and R. Verderber. (1993). Advanced Lighting Guidelines: 1993. Report prepared for the Department of Energy, California Energy Commission, and Electric Power Research Institute. California Energy Commission, Sacramento, California.

Energy Design Resources (EDR). (2000). Building Case Study – Biotech Lab and Office. http://www.energydesignresources.com/

Energy Nexus Group. (2002a). Technology Characterization: Gas Turbines. Arlington, VA. February.

Energy Nexus Group. (2002b). Technology Characterization: Steam Turbines. Arlington, VA. March.

Farrell, J. (1998). New Belgium brewing Company Focuses on Efficiency. Energy Services Bulletin. Western Area Power Administration, Lakewood, Colorado.

Fenning, L. et al. (Eds.) 2001. Pump Life Cycle Costs: A Guide to LCC Analysis for Pumping Systems. Hydraulic Institute/Europump/ United States Department of Energy. ISBN: 1-880952-58-0.

Fiorino, D. P. (2000). Steam Conservation and Boiler Plant Efficiency Advancements. 22nd National Industrial Energy Technology Conference Proceedings. Houston, Texas. April 5-6: 184-202.

Ford Motor Company (2002). Personal communication from corporate energy manager.

Ganapathy, V. (1994). Understand Steam Generator Performance. Chemical Engineering Progress. December.

Greenroofs.com. (2001). Greenroofs 101. Alpharetta, Georgia. http://www.greenroofs.com/

Griffin, B. (2000). The Enbridge Consumers Gas "Steam Saver" Program. 22nd National Industrial Energy Technology Conference Proceedings. Houston, Texas. April 5-6: 203-213.

Hackensellner, T. (2001). Dynamische Niederdruckkochung- Optimierte energie und Verfahrenstechnik. Brauwelt: 17-21.

Hallale, N. (2001). Burning Bright: Trends in Process Integration. Chemical Engineering Progress. July: 30-41.

Holtcamp, W. (2001). A Grass-Roofs Effort, Secret Gardens Conserve Energy and Cool the Air. Sierra Magazine. May/June.

Howe, B. and B. Scales. (1995). Assessing Processes for Compressed Air Efficiency. E-Source Tech Update. November.

Hydraulic Institute. (1994). Efficiency Prediction Method for Centrifugal Pumps. Parsippany, New Jersey.

Hydraulic Institute and Europump. (2001). Pump Life Cycle Costs: A Guide to LCC Analysis for Pumping Systems. Parsippany, New Jersey.

Industrial Assessment Center (IAC). (2003). Industrial Assessment Center Database version 8.1. Rutgers University, New Brunswick, New Jersey. http://iac.rutgers.edu/database/

IMS Health. (2003). IMS World Review 2003. London, UK.

IMS Health. (2005). IMS Health Market Insight. London, UK.
http://www.ims-global.com/insight/insight.htm

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

International Energy Agency (IEA). (2000). Daylight in Buildings: A Sourcebook on Daylighting Systems and Components. Paris: IEA. http://www.iea-shc.org/

Irish Energy Centre (IEC). (2002). Good Practice Case Study 12: Energy Use in Cleanroooms. Dublin, Ireland.

ITT Flygt. (2002). Case Study: Flygt Helps City of Milford Meet the Challenge. Sundbyberg, Sweden. http://www.flygt.com/

Johnston, B. (1995). 5 Ways to Greener Steam. The Chemical Engineer. 594 (August 17): 24-27.

Jones, Ted. (1997). Steam Partnership: Improving Steam Efficiency through Marketplace Partnerships. Proceedings of the 1997 ACEEE Summer Study on Energy Efficiency in Industry. American Council for an Energy-Efficient Economy, Washington, D.C.

Kidger, P. (2001). Personal communication.

Kirk, M. C. Jr. and G. P. Looby. (1996). Energy Conservation and Waste Reduction in the Metal Fabrication Industry. 18th National Industrial Energy Technology Conference Proceedings. Houston, Texas. April 17-18: 1-7.

Konopacki, S., H. Akbari, L. Gartland and L. Rainer. (1998). Demonstration of Energy Savings of Cool Roofs. Lawrence Berkeley National Laboratory, Berkeley, California. Report # LBNL-40673.

Kumana, J. (2000). Pinch Analysis – What, When, Why, How. Additional publications available by contacting jkumana@aol.com.

Lighting Research Center (LRC). (2001). Lighting Futures. LEDs: From Indicators to Illuminators? Rensselaer Polytechnic Institute, Troy, New York. http://www.lrc.rpi.edu/index.asp

Linnhoff, B., D.W. Townsend, D. Boland, G.F. Hewitt, B.E.A. Thomas, A.R. Guy, and R.H. Marsland. (1992). A User Guide on Process Integration for the Efficient Use of Energy. Institution of Chemical Engineers, Rugby, UK.

Linnhoff, B. (1993). Pinch Analysis: A State-of-the-Art Overview. Chemical Engineering (71): 503-522.

Lom and Associates. (1998). Energy Guide: Energy Efficiency Opportunities in the Canadian Brewing Industry. Brewers Association of Canada, Ontario, Canada.

Martin, N., M. Ruth, L. Price, R. N. Elliott, A. M. Shipley, and J. Thorne. (2000). Emerging Energy-Efficient Industrial Technologies. American Council for an Energy-Efficient Economy, Washington, D.C. October.

McKane, A.. J. P. Ghislain, and K. Meadows (1999). Compressed Air Challenge: Market Change from the Inside Out. Proceedings of the 1999 ACEEE Summer Study on Energy Efficiency in Industry. Saratoga Springs, New York, 15-18 June 1999. LBNL-43882.

McPherson, G., and J.R. Simpson. (1995). Shade Trees as a Demand-Side Resource. Home Energy. March/April.

Merck and Company, Inc. (2005). Personal communication with Helene Ferm, Rahway Site Energy Team, Rahway, New Jersey, September 7th.

Michaelson, D. A. and F. T. Sparrow. (1995). Energy Efficiency in the Metals Fabrication Industries. Proceedings of the 1995 ACEEE Summer Study on Energy Efficiency in Industry, Partnerships, Productivity, and the Environment, New York. American Council for an Energy-Efficient Economy, Washington, D.C.

Mills, E., G. Bell, D. Sartor, A. Chen, D. Avery, M. Siminovitch, S. Greenberg, G. Marton, A. de Almeida, and L.E. Lock. (1996). Energy Efficiency in California Laboratory-Type Facilities. Lawrence Berkeley National Laboratory, Berkeley, California. Report # LBNL-39061.

Mills, E., and D. Sartor. (2004). Energy Use and Savings Potential for Laboratory Fume Hoods. Energy (30):1859–1864.

Motor Decisions Matter (MDM) (2007). Motor Planning Kit. Boston, Massachusetts. http://www.motorsmatter.org/tools/mpkv21.pdf

Nadel, S., R.N. Elliott, M. Shephard, S. Greenberg, G. Katz and A.T. de Almeida (2002). Energy-Efficient Motor Systems: A Handbook on Technology, Program and Policy Opportunities. American Council for an Energy-Efficient Economy, Washington, D.C.

National Bureau of Economic Research. (2000). Manufacturing Industry Database. National Bureau of Economic Research, Cambridge, Massachusetts. http://www.nber.org/nberces/.

National Electrical Manufacturers Association (NEMA). (2001). Motor and Generator Section. Rosslyn, Virginia.
http://www.nema.org/prod/ind/motor/

National Electrical Manufacturers Association (NEMA) (2002). NEMA Standards Publication No. MG-1, Motors and Generators, Revision 3. Rosslyn, Virginia.

Nini, D., and P Gimenez-Mitsotakis. (1994). Creative Solutions for Bakery Waste Effluent. American Institute of Chemical Engineers, Symposium Series, No. 300, Vol. 90: 95-105.

Novartis AG. (2004). Target and Results - Energy and water consumption. Novartis Health, Safety, and Environment, Corporate Citizenship. Basel, Switzerland. http://www.novartis.com/corporate_citizenship/en/hse_energy_water_cons.shtml

Parekh, P. (2000). Investment Grade Compressed Air System Audit, Analysis and Upgrade. 22nd National Industrial Energy Technology Conference Proceedings. Houston, Texas. April 5-6: 270-279.

Pfizer. (2001). 2000 Environmental, Health, and Safety Report. New York, New York.

Polley, G.T. and H.L. Polley. (2000). Design Better Water Networks. Chemical Engineering Progress. February: 47-52.

Pollution Engineering. (2002). Casebook: National Raisin Cuts Wastewater Costs and Protects Environment. Pollution Engineering. September. http://www.pollutionengineering.com/

Portland Energy Conservation, Inc (PECI). (1999). Fifteen O&M Best Practices for Energy-Efficient Buildings. Prepared for the U.S. Environmental Protection Agency and U.S. Department of Energy. Portland, Oregon.

Price, A. and M. H. Ross. (1989). Reducing Industrial Electricity Costs – an Automotive Case Study. The Electricity Journal. July: 40-51.

Pharmaceutical Industry Association of Puerto Rico (PIAPR). (2005). About Us. Guaynabo, Puerto Rico. http://www.piapr.com/

Radgen, P. and E. Blaustein (Eds.). (2001). Compressed Air Systems in the European Union, Energy, Emissions, Savings Potential and Policy Actions. LOG_X Verlag, GmbH, Stuttgart, Germany.

RC Associates Distributing, LLC. (2002). The Automatic Sash Positioning System Provides Energy and Capital Savings. Saginaw, Michigan.
http://www.newtechtm.com/ASPSenergy.html

Roberson, J. A., C. A. Webber, M. C. McWhinney, R. E. Brown, M. J. Pinckard, and J. F. Busch. (2004). After-hours Power Status of Office Equipment and Energy Use of Miscellaneous Plug-Load Equipment. Lawrence Berkeley National Laboratory, Berkeley, California. Report # LBNL-53729-Revised.

San Diego Regional Energy Office (SDREO). (2004). J&JPRD Powers R&D Facility Expansion with New Green Cogeneration System. San Diego, California. http://www.sdenergy.org/ContentPage.asp?ContentID=257&SectionID=252&SectionTarget=78#success

Scales, B. (2002). Personal written communication.

Scales, W., and D. M. McCulloch (2007) Best Practices for Compressed Air Systems- Second Edition, Compressed Air Challenge®. Washington, DC. http://www.compressedairchallenge.org/

Scott, Doug, 2004. Personal communication with Doug Scott, PG&E Consultant, November 2004.

Sellers L.J. (2003). Fourth Annual Pharm Exec 50. Pharmaceutical Executive. May: 42-52.

Sezgen, O. and J. G. Koomey. (2000). Interaction between Lighting and Space Condition Energy Use in U.S. Commercial Buildings. Energy (25): 793-805.

Shenoy, U. (1994). Heat Exchanger Network Synthesis. Gulf Publishing Company, Houston, Texas.

Smith, R. (1995). Chemical Process Design. McGraw-Hill Inc., New York, New York.

Southern California Edison (SCE). (2003) Saving Money with Motors in Pharmaceutical Plants. Southern California Edison Educational Publication. Rosemead, California. http://cee1.org/ind/mot-sys/Pharm_Bro.pdf

Srikanth, G. (2004). Membrane Separation Processes – Technology and Business Opportunities. News and Views. Technology Information, Forecasting & Assessment Council (TIFAC), New Delhi, India.

Tetley, P.A. (2001). Cutting Energy Costs with Laboratory Workstation Fume Hood Exhaust. Pharmaceutical Engineering. 21 (5): 90-97.

Toyota Motor Corporation. (2002). Personal communication with Brad Reed, Toyota Motor Manufacturing of North America, May 2002.

Tschudi, W. F., K. Benschine, S. Fok, and P. Rumsey. (2001). Cleanroom Energy Benchmark in High-tech and Biotech Industries. Proceedings of the 2001 ACEEE Summer Study on Energy Efficiency in Industry. American Council for an Energy-Efficient Economy, Washington, D.C.

Tschudi, W. F., D. Sartor, E. Mills, and T. Xu. (2002). High-Performance Laboratories and Cleanrooms. Lawrence Berkeley National Laboratory, Berkeley, California. Report # LBNL-50599.

Tschudi, W. F. and T. Xu. (2003). Cleanroom Energy Benchmarking Results. Proceedings of the 2003 ASHRAE Annual Meeting, Kansas City, Missouri. American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), Atlanta, Georgia.

Tutterow, V. (1999). Energy Efficiency in Pumping Systems: Experience and Trends in the Pulp and Paper Industry. Proceedings of the 1999 ACEEE Summer Study on Energy Efficiency in Industry. American Council for an Energy-Efficient Economy, Washington, D.C

United Lab Equipment, Inc. (2001). Bi-stable Vortex II Fume Hood. Depew, New York.

United States Census. (1990). 1988 Statistics for Industry Groups and Industries. United States Census Bureau, Washington, D.C. Report # M88 (AS)-1.

United States Census. (1993). 1991 Statistics for Industry Groups and Industries. United States Census Bureau, Washington, D.C. Report # M91 (AS)-1.

United States Census. (1995). 1993 Statistics for Industry Groups and Industries. United States Census Bureau, Washington, D.C. Report # M93(AS)-1.

United States Census. (1996). 1994 Statistics for Industry Groups and Industries. United States Census Bureau, Washington, D.C. Report # M94(AS)-1.

United States Census. (1998). 1996 Statistics for Industry Groups and Industries. United States Census Bureau, Washington, D.C. Report # M96(AS)-1.

United States Census. (2000). 1997 Economic Census of Outlying Areas, Manufacturing, Puerto Rico. United States Census Bureau, Washington, D.C. Report # OA97E-4.

United States Census. (2001). 1999 Statistics for Industry Groups and Industries. United States Census Bureau, Washington, D.C. Report # M99(AS)-1 (RV).

United States Census. (2003). 2001 Statistics for Industry Groups and Industries. United States Census Bureau, Washington, D.C. Report # M01(AS)-1.

United States Census. (2005a). 2003 Statistics for Industry Groups and Industries. United States Census Bureau, Washington, D.C. Report # M03(AS)-1 (RV).

United States Census. (2005b). 2002 Economic Census, Industry Series, Medicinal and Botanical Manufacturing. United States Census Bureau, Washington, D.C. Report # EC02-31I-325411 (RV).

United States Census. (2005c). 2002 Economic Census, Industry Series, Pharmaceutical Preparation Manufacturing. United States Census Bureau, Washington, D.C. Report # EC02-31I-325412 (RV).

United States Census. (2005d). 2002 Economic Census, Industry Series, In-Vitro Diagnostic Substance Manufacturing. United States Census Bureau, Washington, D.C. Report # EC02-31I-325413 (RV).

United States Census. (2005e). 2002 Economic Census, Industry Series, Biological Product (Except Diagnostic) Manufacturing. United States Census Bureau, Washington, D.C. Report # EC02-31I-325414 (RV).

United States Department of Energy (DOE) (1996). Replacing an Oversized and Underloaded Electric Motor. Office of Energy Efficiency and Renewable Energy, Industrial Technologies Program, Washington, D.C. Fact Sheet DOE/GO-10096-287.

United States Department of Energy (DOE). (1997). What's New in Building Energy Efficiency – Selecting Windows for Energy Efficiency. Office of Energy Efficiency and Renewable Energy, Building Technology Program. Washington, D.C.

United States Department of Energy (DOE). (1998). Improving Compressed Air System Performance - A Sourcebook for Industry. Office of Industrial Technologies, Energy Efficiency and Renewable Energy. Washington, D.C.

United States Department of Energy (DOE). (1999). 1999 Commercial Buildings Energy Consumption Survey (CBECS). Energy Information Administration, Washington, D.C.

United States Department of Energy (DOE). (2000). Best Practices. – Improved Steam Trap Maintenance Increases System Performance and Decreases Operating Costs. Office of Industrial Technologies, Energy Efficiency and Renewable Energy. Washington, D.C.

United States Department of Energy (DOE). (2001a). Best Practices Program. Office of Industrial Technologies, Energy Efficiency and Renewable Energy, Washington, D.C. http://www.oit.doe.gov/bestpractices/

United States Department of Energy (DOE). (2001b). Best Practices. – Compressed Air System Renovation Project Improves Production at a Food Processing Facility. Office of Industrial Technologies, Energy Efficiency and Renewable Energy. Washington, D.C.

United States Department of Energy (DOE). (2001c). Showcase Demonstration - The Challenge: Improving The Efficiency of A Brewery's Cooling System. Office of Industrial Technologies, Energy Efficiency and Renewable Energy. Washington, D.C. http://www.oit.doe.gov/bestpractices/motors/mc-cs12.shtml.

United States Department of Energy (DOE). (2001d). Information on Steam. Office of Industrial Technologies, Energy Efficiency and Renewable Energy, Washington, D.C. http://www.oit.doe.gov/bestpractices/steam/

United States Department of Energy (DOE). (2002a). Insulation Fact Sheet – Introduction. Energy Office of Industrial Technologies, Energy Efficiency and Renewable Energy. Washington, D.C.

United States Department of Energy (DOE). (2002b). Best Practices. – Optimization Electric Motor System at a Corporate Campus Facility. Office of Industrial Technologies, Energy Efficiency and Renewable Energy. Washington, D.C.

United States Department of Energy (DOE). (2003). Energy Matters Newsletter. Office of Industrial Technologies, Energy Efficiency and Renewable Energy. Washington, D.C. http://www.oit.doe.gov/bestpractices/energymatters/fall2003_absorption.shtml

United States Department of Energy (DOE). (2003b). Laboratories for the 21st Century: Best Practice Guide Daylighting for Laboratories. Washington, D.C. See also: http://www.labs21century.gov/pdf/bp_daylight_508.pdf

United States Department of Energy (DOE) (2004a). Energy Tips – Compressed Air: Remove Condensate with Minimal Air Loss. Office of Energy Efficiency and Renewable Energy, Industrial Technologies Program, Washington, D.C. Compressed Air Tip Sheet #13.

United States Department of Energy (DOE) (2004b). Energy Tips – Compressed Air: Eliminate Inappropriate Uses of Compressed Air. Office of Energy Efficiency and Renewable Energy, Industrial Technologies Program, Washington, D.C. Compressed Air Tip Sheet #2.

United States Department of Energy (DOE) (2004c). Energy Tips – Compressed Air: Alternative Strategies for Low-Pressure End Uses. Office of Energy Efficiency and Renewable Energy, Industrial Technologies Program, Washington, D.C. Compressed Air Tip Sheet #11.

United States Department of Energy (DOE). (2005). Energy Tips: Estimate Voltage Unbalance. Information Sheet. Office of Industrial Technologies, Washington, DC. Motor Systems Tip Sheet #7.

United States Department of Energy (DOE) (2006). Improving Pumping System Performance, A Sourcebook for Industry. Office of Energy Efficiency and Renewable Energy, Industrial Technologies Program, Washington, D.C. Report DOE/GO-102006-2079.

United States Department of Energy (DOE) and Compressed Air Challenge (CAC) (2003). Improving Compressed Air System Performance - A Sourcebook for Industry. Office of Industrial Technologies, Washington, D.C.

United States Environmental Protection Agency (EPA). (1997). EPA Office of Compliance Sector Notebook Project: Profile of the Pharmaceutical Manufacturing Industry. Office of Compliance, Washington, D.C.

United States Environmental Protection Agency (EPA) (2001). Green Lights Program. United States Environmental Protection Agency, Washington, D.C. http://www.energystar.gov/index.cfm?c=lighting.pr_lighting

United States Environmental Protection Agency (EPA). (2004). ENERGY STAR Building Upgrade Manual. Office of Air and Radiation, Washington, D.C.: EPA. http://www.energystar.gov/ia/business/BUM.pdf

United States Environmental Protection Agency (EPA). (2005). Guidelines for Energy Management. Washington, D.C.
http://www.energystar.gov/index.cfm?c=guidelines.guidelines_index

United States Environmental Protection Agency and Department of Energy (U.S. EPA/DOE). (2000). An Introduction to Low-energy Design. Laboratories for the 21st Century. http://www.labs21century.gov/

United States Environmental Protection Agency and Department of Energy (U.S. EPA/DOE). (2001a). Case Studies – Fred Hutchinson Cancer Research Center, Seattle, Washington. Laboratories for the 21st Century. http://www.labs21century.gov/

United States Environmental Protection Agency and Department of Energy (U.S. EPA/DOE). (2001b). Case Studies – the Louis Stokes Laboratories, Building 50, National Institute of Health, Bethesda, Maryland. Laboratories for the 21st Century. http://www.labs21century.gov/

United States Environmental Protection Agency and Department of Energy (U.S. EPA/DOE). (2001c). Case Studies – Process and Environmental Technology Laboratory of Sandia National Laboratories, New Mexico. Laboratories for the 21st Century. http://www.labs21century.gov/

United States Environmental Protection Agency and Department of Energy (U.S. EPA/DOE). (2002a). Case Studies – Pharmacia Building Q, Skokie, Illinois. Laboratories for the 21st Century. http://www.labs21century.gov/

United States Environmental Protection Agency and Department of Energy (U.S. EPA/DOE). (2003). Best Practices - Energy Recovery for Ventilation Air in Laboratories. Laboratories for the 21st Century. http://www.labs21century.gov/

United States Environmental Protection Agency and Department of Energy (U.S. EPA/DOE). (2005). Energy Benchmarking. Laboratories for the 21st Century. http://www.labs21century.gov/toolkit/benchmarking.htm

Wiesner, M.R. and S. Chellam. (1999). The Promise of Membrane Technology. Environmental Science and Technology 33(17): 360-366A.

Worrell, E., J.W. Bode, and J.G. de Beer. (1997). Energy Efficient Technologies in Industry - Analysing Research and Technology Development Strategies - The 'Atlas' Project. Department of Science, Technology & Society, Utrecht University, Utrecht, the Netherlands.

Wu, G. (2000). Design and Retrofit of Integrated Refrigeration Systems. Ph.D. Thesis, The University of Manchester, Manchester, UK.

Wyeth. (2004). Awards and Recognition: External Recognition. Madison, New Jersey. http://www.wyeth.com/EHS/performance/awards.asp

Xenergy, Inc. (1998). United States Industrial Electric Motor Systems Market Opportunities Assessment. Prepared for the United States Department of Energy's Office of Industrial Technology and Oak Ridge National Laboratory. Burlington, Massachusetts.

Zeitz, Ronald A. (ed.). (1997). CIBO Energy Efficiency Handbook. Council of Industrial Boiler Owners, Burke, Virginia.

9. Glossary

ACH	Air changes per hour
ASD	Adjustable speed drive
Btu	British Thermal Units
CAV	Constant-air-volume
cGMP	Current Good Manufacturing Practices
cfm	Cubic feet per minute
CHP	Combined heat and power
CIPEC	Canadian Industry Program for Energy Conservation
CO	Carbon monoxide
CO_2	Carbon dioxide
COP	Coefficient of performance
DX	Direct expansion
EASA	Electrical Apparatus Service Association
ft^2	Square feet
GWh	Gigawatt-hour
HACCP	Hazard Analysis and Critical Control Point
HEPA	High efficiency particulate air
HHV	Higher heating value
HID	High-intensity discharge
hp	Horsepower
HVAC	Heating, ventilation, and air conditioning
IAC	Industrial Assessment Center
ISO	International Organization for Standardization

kWh	Kilowatt-hour
LED	Light-emitting diode
Low-E	Low emittance
m^3	Cubic meter
MASIS	Mobile aerosol-sealant injection system
MBtu	Million British Thermal Units
MW	Megawatt
MWh	Megawatt-hour
NAICS	North American Industry Classification System
NDA	New Drug Application
NEMA	National Electrical Manufacturers Association
NO_x	Nitrogen oxides
OSHA	Occupational Safety and Health Administration
PM	Preventive maintenance
psi	Pounds per square inch
psig	Pounds per square inch (gauge)
R&D	Research and development
STIG	Steam-injected gas turbine
ULPA	Ultra low penetration air
U.S. DOE	United States Department of Energy
U.S. EPA	United States Environmental Protection Agency
U.S. FDA	United States Food and Drug Administration
VAV	Variable-air-volume
W	Watt

Appendix A: Basic Energy Efficiency Actions for Plant Personnel

Personnel at all levels should be aware of energy use and organizational goals for energy efficiency. Staff should be trained in both skills and general approaches to energy efficiency in day-to-day practices. In addition, performance results should be regularly evaluated and communicated to all personnel, recognizing high achievement. Some examples of simple tasks employees can do are outlined below (Caffal 1995).

- Eliminate unnecessary energy consumption by equipment. Switch off motors, fans, and machines when they are not being used, especially at the end of the working day or shift, and during breaks, when it does not affect production, quality, or safety. Similarly, turn on equipment no earlier than needed to reach the correct settings (temperature, pressure) at the start time.

- Switch off unnecessary lights; rely on daylighting whenever possible.

- Use weekend and night setbacks on HVAC in offices or conditioned buildings.

- Report leaks of water (both process water and dripping taps), steam, and compressed air. Ensure they are repaired quickly. The best time to check for leaks is a quiet time like the weekend.

- Look for unoccupied areas being heated or cooled, and switch off heating or cooling.

- Check that heating controls are not set too high or cooling controls set too low. In this situation, windows and doors are often left open to lower temperatures instead of lowering the heating.

- Check to make sure the pressure and temperature of equipment is not set too high.

- Prevent drafts from badly fitting seals, windows and doors, and hence, leakage of cool or warm air.

- Carry out regular maintenance of energy-consuming equipment.

- Ensure that the insulation on process heating equipment is effective.

Appendix B: ENERGY STAR Energy Management Program Assessment Matrix

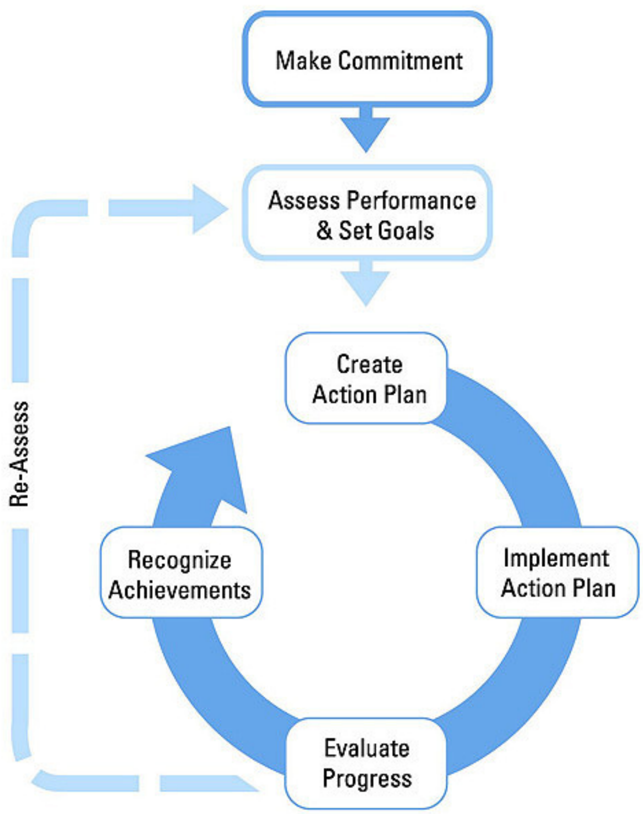
CHANGE FOR THE BETTER WITH ENERGY STAR

Energy Management Program Assessment Matrix

Introduction

The U.S. EPA has developed guidelines for establishing and conducting an effective energy management program based on the successful practices of ENERGY STAR partners.

These guidelines, illustrated in the graphic, are structured on seven fundamental management elements that encompass specific activities.



This assessment matrix is designed to help organizations and energy managers compare their energy management practices to those outlined in the Guidelines. The full Guidelines can be viewed on the ENERGY STAR web site – http://www.energystar.gov/.

How To Use The Assessment Matrix

The matrix outlines the key activities identified in the ENERGY STAR Guidelines for Energy Management and three levels of implementation:

- No evidence
- Most elements
- Fully Implemented

1. Print the assessment matrix.

2. Compare your program to the Guidelines by identifying the degree of implementation that most closely matches your organization's program.

3. Use a highlighter to fill in the cell that best characterizes the level of implementation of your program. You will now have a visual comparison of your program to the elements of the ENERGY STAR Guidelines for Energy Management.

4. Identify the steps needed to fully implement the energy management elements and record these in the Next Steps column.

Energy Management Program Assessment Matrix				
	Little or no evidence	**Some elements**	**Fully implemented**	**Next Steps**
Make Commitment to Continuous Improvement				
Energy Director	No central corporate resource Decentralized management	Corporate or organizational resource not empowered	Empowered corporate leader with senior management support	
Energy Team	No company energy network	Informal organization	Active cross-functional team guiding energy program	
Energy Policy	No formal policy	Referenced in environmental or other policies	Formal stand-alone EE policy endorsed by senior mgmt.	
Assess Performance and Opportunities				
Gather and Track Data	Little metering/no tracking	Local or partial metering/tracking/ reporting	All facilities report for central consolidation/analysis	
Normalize	Not addressed	Some unit measures or weather adjustments	All meaningful adjustments for corporate analysis	
Establish baselines	No baselines	Various facility-established	Standardized corporate base year and metric established	
Benchmark	Not addressed or only same site historical comparisons	Some internal comparisons among company sites	Regular internal & external comparisons & analyses	
Analyze	Not addressed	Some attempt to identify and correct spikes	Profiles identifying trends, peaks, valleys & causes	
Technical assessments and audits	Not addressed	Internal facility reviews	Reviews by multi-functional team of professionals	
Set Performance Goals				
Determine scope	No quantifiable goals	Short term facility goals or nominal corporate goals	Short & long term facility and corporate goals	
Estimate potential for improvement	No process in place	Specific projects based on limited vendor projections	Facility & corporate defined based on experience	
Establish goals	Not addressed	Loosely defined or sporadically applied	Specific & quantifiable at various organizational levels	
Create Action Plan				
Define technical steps and targets	Not addressed	Facility-level consideration as opportunities occur	Detailed multi-level targets with timelines to close gaps	
Determine roles and resources	Not addressed or done on ad hoc basis	Informal interested person competes for funding	Internal/external roles defined & funding identified	

Energy Management Program Assessment Matrix

	Little or no evidence	Some elements	Fully implemented	Next Steps
Implement Action Plan				
Create a communication plan	Not addressed	Tools targeted for some groups used occasionally	All stakeholders are addressed on regular basis	
Raise awareness	No promotion of energy efficiency	Periodic references to energy initiatives	All levels of organization support energy goals	
Build capacity	Indirect training only	Some training for key individuals	Broad training/certification in technology & best practices	
Motivate	No or occasional contact with energy users and staff	Threats for non-performance or periodic reminders	Recognition, financial & performance incentives	
Track and monitor	No system for monitoring progress	Annual reviews by facilities	Regular reviews & updates of centralized system	
Evaluate Progress				
Measure results	No reviews	Historical comparisons	Compare usage & costs vs. goals, plans, competitors	
Review action plan	No reviews	Informal check on progress	Revise plan based on results, feedback & business factors	
Recognize Achievements				
Provide internal recognition	Not addressed	Identify successful projects	Acknowledge contributions of individuals, teams, facilities	
Get external recognition	Not sought	Incidental or vendor acknowledgement	Government/third party highlighting achievements	

Interpreting Your Results

Comparing your program to the level of implementation identified in the Matrix should help you identify the strengths and weaknesses of your program.

The U.S. EPA has observed that organizations fully implementing the practices outlined in the Guidelines achieve the greatest results. Organizations are encouraged to implement the Guidelines as fully as possible.

By highlighting the cells of the matrix, you now can easily tell how well balanced your energy program is across the management elements of the Guidelines. Use this illustration of your energy management program for discussion with staff and management.

Use the "Next Steps" column of the Matrix to develop a plan of action for improving your energy management practices.

Resources and Help

ENERGY STAR offers a variety tools and resources to help organizations strengthen their energy management programs.

Here are some next steps you can take with ENERGY STAR:

1. Read the Guidelines sections for the areas of your program that are not fully implemented.

2. Become an ENERGY STAR Partner, if you are not already.

3. Review ENERGY STAR Tools and Resources.

4. Find more sector-specific energy management information at http://www.energystar.gov/industry.

5. Contact ENERGY STAR for additional resources.

Appendix C: Support Programs for Industrial Energy Efficiency Improvement

This appendix provides a list of energy efficiency support available to industry. A brief description of the program or tool is given, as well as information on its target audience and the URL for the program. Included are federal and state programs. Use the URL to obtain more information from each of these sources. An attempt was made to provide as complete a list as possible; however, information in this listing may change with the passage of time.

Tools for Self-Assessment

Steam System Assessment Tool

Description: Software package to evaluate energy efficiency improvement projects for steam systems. It includes an economic analysis capability.
Target Group: Any industry operating a steam system
Format: Downloadable software package (13.6 MB)
Contact: U.S. Department of Energy
URL: http://www1.eere.energy.gov/industry/bestpractices/software.html

Steam System Scoping Tool

Description: Spreadsheet tool for plant managers to identify energy efficiency opportunities in industrial steam systems.
Target Group: Any industrial steam system operator
Format: Downloadable software (Excel)
Contact: U.S. Department of Energy
URL: http://www1.eere.energy.gov/industry/bestpractices/software.html

3E Plus: Optimization of Insulation of Boiler Steam Lines

Description: Downloadable software to determine whether boiler systems can be optimized through the insulation of boiler steam lines. The program calculates the most economical thickness of industrial insulation for a variety of operating conditions. It makes calculations using thermal performance relationships of generic insulation materials included in the software.
Target Group: Energy and plant managers
Format: Downloadable software
Contact: U.S. Department of Energy
URL: http://www1.eere.energy.gov/industry/bestpractices/software.html

MotorMaster+

Description: Energy-efficient motor selection and management tool, including a catalog of over 20,000 AC motors. It contains motor inventory management tools, maintenance log tracking, efficiency analysis, savings evaluation, energy accounting, and environmental reporting capabilities.
Target Group: Any industry
Format: Downloadable software (can also be ordered on CD)
Contact: U.S. Department of Energy
URL: http://www1.eere.energy.gov/industry/bestpractices/software.html

ASDMaster: Adjustable Speed Drive Evaluation Methodology and Application

Description:	Software program helps to determine the economic feasibility of an adjustable speed drive application, predict how much electrical energy may be saved by using an ASD, and search a database of standard drives.
Target Group:	Any industry
Format:	Software package (not free)
Contact:	Electric Power Research Institute (EPRI), (800) 832-7322
URL:	http://www.epri-peac.com/products/asdmaster/asdmaster.html

The 1-2-3 Approach to Motor Management

Description:	A step-by-step motor management guide and spreadsheet tool that can help motor service centers, vendors, utilities, energy-efficiency organizations, and others convey the financial benefits of sound motor management.
Target Group:	Any industry
Format:	Downloadable Microsoft Excel spreadsheet
Contact:	Consortium for Energy Efficiency (CEE), (617) 589-3949
URL:	http://www.motorsmatter.org/tools/123approach.html

AirMaster+: Compressed Air System Assessment and Analysis Software

Description:	Modeling tool that maximizes the efficiency and performance of compressed air systems through improved operations and maintenance practices
Target Group:	Any industry operating a compressed air system
Format:	Downloadable software
Contact:	U.S. Department of Energy
URL:	http://www1.eere.energy.gov/industry/bestpractices/software.html

Fan System Assessment Tool (FSAT)

Description:	The Fan System Assessment Tool (FSAT) helps to quantify the potential benefits of optimizing a fan system. FSAT calculates the amount of energy used by a fan system, determines system efficiency, and quantifies the savings potential of an upgraded system.
Target Group:	Any user of fans
Format:	Downloadable software
Contact:	U.S. Department of Energy
URL:	http://www1.eere.energy.gov/industry/bestpractices/software.html

Combined Heat and Power Application tool (CHP)

Description:	The Combined Heat and Power Application Tool (CHP) helps industrial users evaluate the feasibility of CHP for heating systems such as fuel-fired furnaces, boilers, ovens, heaters, and heat exchangers.
Target Group:	Any industrial heat and electricity user
Format:	Downloadable software
Contact:	U.S. Department of Energy
URL:	http://www1.eere.energy.gov/industry/bestpractices/software.html

Pump System Assessment Tool 2004 (PSAT)

Description:	The tool helps industrial users assess the efficiency of pumping system operations. PSAT uses achievable pump performance data from Hydraulic Institute standards and motor performance data from the MotorMaster+ database to calculate potential energy and associated cost savings.
Target Group:	Any industrial pump user
Format:	Downloadable software
Contact:	U.S. Department of Energy
URL:	http://www1.eere.energy.gov/industry/bestpractices/software.html

Quick Plant Energy Profiler

Description:	The Quick Plant Energy Profiler, or Quick PEP, is an online software tool provided by the U.S. Department of Energy to help industrial plant managers in the United States identify how energy is being purchased and consumed at their plant and also identify potential energy and cost savings. Quick PEP is designed so that the user can complete a plant profile in about an hour. The Quick PEP online tutorial explains what plant information is needed to complete a Quick PEP case.
Target Group:	Any industrial plant
Format:	Online software tool
Contact:	U.S. Department of Energy
URL:	http://www1.eere.energy.gov/industry/bestpractices/software.html

ENERGY STAR Portfolio Manager

Description:	Online software tool helps to assess the energy performance of buildings by providing a 1-100 ranking of a building's energy performance relative to the national building market. Measured energy consumption forms the basis of the ranking of performance.
Target Group:	Any building user or owner
Format:	Online software tool
Contact:	U.S. Environmental Protection Agency
URL:	http://www.energystar.gov/index.cfm?c=evaluate_performance.bus_portfoliomanager

Assessment and Technical Assistance

Industrial Assessment Centers

Description:	Small- to medium-sized manufacturing facilities can obtain a free energy and waste assessment. The audit is performed by a team of engineering faculty and students from 30 participating universities in the U.S. and assesses the plant's performance and recommends ways to improve efficiency.
Target Group:	Small- to medium-sized manufacturing facilities with gross annual sales below $75 million and fewer than 500 employees at the plant site.
Format:	A team of engineering faculty and students visits the plant and prepares a written report with energy efficiency, waste reduction and productivity recommendations.
Contact:	U.S. Department of Energy
URL:	http://www1.eere.energy.gov/industry/bestpractices/iacs.html

Save Energy Now Assessments

Description:	The U.S. DOE conducts plant energy assessments to help manufacturing facilities across the nation identify immediate opportunities to save energy and money, primarily by focusing on energy-intensive systems, including process heating, steam, pumps, fans, and compressed air.
Target Group:	Large plants
Format:	Online request
Contact:	U.S. Department of Energy
URL:	http://www1.eere.energy.gov/industry/saveenergynow/

Manufacturing Extension Partnership (MEP)

Description:	MEP is a nationwide network of not-for-profit centers in over 400 locations providing small- and medium-sized manufacturers with technical assistance. A center provides expertise and services tailored to the plant, including a focus on clean production and energy-efficient technology.
Target Group:	Small- and medium-sized plants
Format:	Direct contact with local MEP Office
Contact:	National Institute of Standards and Technology, (301) 975-5020
URL:	http://www.mep.nist.gov/

Small Business Development Center (SBDC)

Description:	The U.S Small Business Administration (SBA) administers the Small Business Development Center Program to provide management assistance to small businesses through 58 local centers. The SBDC Program provides counseling, training and technical assistance in the areas of financial, marketing, production, organization, engineering and technical problems and feasibility studies, if a small business cannot afford consultants.
Target Group:	Small businesses
Format:	Direct contact with local SBDC
Contact:	Small Business Administration, (800) 8-ASK-SBA
URL:	http://www.sba.gov/sbdc/

ENERGY STAR – Selection and Procurement of Energy-Efficient Products for Business

Description:	ENERGY STAR identifies and labels energy-efficient office equipment. Look for products that have earned the ENERGY STAR. They meet strict energy efficiency guidelines set by the EPA. Office equipment included such items as computers, copiers, faxes, monitors, multifunction devices, printers, scanners, transformers and water coolers.
Target Group:	Any user of labeled equipment.
Format:	Website
Contact:	U.S. Environmental Protection Agency
URL:	http://www.energystar.gov/index.cfm?c=business.bus_index

Training

ENERGY STAR

Description:	As part of ENERGY STAR's work to promote superior energy management systems, energy managers for the companies that participate in ENERGY STAR are offered the opportunity to network with other energy managers in the partnership. The networking meetings are held monthly and focus on a specific strategic energy management topic to train and strengthen energy managers in the development and implementation of corporate energy management programs.
Target Group:	Corporate and plant energy managers
Format:	Web-based teleconference
Contact:	Climate Protection Partnerships Division, U.S. Environmental Protection Agency
URL:	http://www.energystar.gov/

Best Practices Program

Description:	The U.S. DOE Best Practices Program provides training and training materials to support the efforts of the program in efficiency improvement of utilities (compressed air, steam) and motor systems (including pumps). Training is provided regularly in different regions. One-day or multi-day trainings are provided for specific elements of the above systems. The Best Practices program also provides training on other industrial energy equipment, often in coordination with conferences.
Target Group:	Technical support staff, energy and plant managers
Format:	Various training workshops (one day and multi-day workshops)
Contact:	Office of Industrial Technologies, U.S. Department of Energy
URL:	http://www1.eere.energy.gov/industry/bestpractices/training.html

Compressed Air Challenge®

Description:	The not-for-profit Compressed Air Challenge® develops and provides training on compressed air system energy efficiency via a network of sponsoring organizations in the United States and Canada. Three levels of training are available: (1) Fundamentals (1 day); (2) Advanced (2 days); and (3) Qualified Specialist (3-1/2 days plus an exam). Training is oriented to support implementation of an action plan at an industrial facility.
Target Group:	Compressed air system managers, plant engineers
Format:	Training workshops
Contact:	Compressed Air Challenge: Info@compressedairchallenge.org
URL:	http://www.compressedairchallenge.org/

Financial Assistance

Below major federal programs are summarized that provide assistance for energy efficiency investments. Many states also offer funds or tax benefits to assist with energy efficiency projects (see below for State Programs). However, these programs can change over time, so it is recommended to review current policies when making any financial investment decisions.

Industries of the Future - U.S. Department of Energy

Description:	Collaborative R&D partnerships in nine vital industries. The partnership consists of the development of a technology roadmap for the specific sector and key technologies, and cost-shared funding of research and development projects in these sectors.
Target Group:	Nine selected industries: agriculture, aluminum, chemicals, forest products, glass, metal casting, mining, petroleum and steel.
Format:	Solicitations (by sector or technology)
Contact:	U.S. Department of Energy – Office of Industrial Technologies
URL:	http://www.eere.energy.gov/industry/technologies/industries.html

Inventions & Innovations (I&I)

Description:	The program provides financial assistance through cost-sharing of 1) early development and establishing technical performance of innovative energy-saving ideas and inventions (up to $75,000) and 2) prototype development or commercialization of a technology (up to $250,000). Projects are performed by collaborative partnerships and must address industry-specified priorities.
Target Group:	Any industry (with a focus on energy-intensive industries)
Format:	Solicitation
Contact:	U.S. Department of Energy – Office of Industrial Technologies
URL:	http://www.eere.energy.gov/inventions/

Small Business Administration (SBA)

Description:	The Small Business Administration provides several loan and loan guarantee programs for investments (including energy-efficient process technology) for small businesses.
Target Group:	Small businesses
Format:	Direct contact with SBA
Contact:	Small Business Administration
URL:	http://www.sba.gov/

State and Local Programs

Many state and local governments have general industry and business development programs that can be used to assist businesses in assessing or financing energy-efficient process technology or buildings. Please contact your state and local government to determine what tax benefits, funding grants, or other assistance they may be able to provide your organization. This list should not be considered comprehensive but instead merely a short list of places to start in the search for project funding. These programs can change over time, so it is recommended to review current policies when making any financial investment decisions.

Summary of Motor and Drive Efficiency Programs by State

Description:	A report that provides an overview of state-level programs that support the use of NEMA Premium® motors, ASDs, motor management services, system optimization and other energy management strategies.
Target Group:	Any industry
Contact:	Consortium for Energy Efficiency (CEE), (617) 589-3949
URL:	http://www.motorsmatter.org/tools/123approach.html

California – Public Interest Energy Research (PIER)

Description:	PIER provides funding for energy efficiency, environmental, and renewable energy projects in the state of California. Although there is a focus on electricity, fossil fuel projects are also eligible.
Target Group:	Targeted industries (e.g. food industries) located in California
Format:	Solicitation
Contact:	California Energy Commission, (916) 654-4637
URL:	http://www.energy.ca.gov/pier/funding.html

California – Energy Innovations Small Grant Program (EISG)

Description:	EISG provides small grants for development of innovative energy technologies in California. Grants are limited to $75,000.
Target Group:	All businesses in California
Format:	Solicitation
Contact:	California Energy Commission, (619) 594-1049
URL:	http://www.energy.ca.gov/research/innovations/index.html/

California – Savings By Design

Description:	Design assistance is available to building owners and to their design teams for energy-efficient building design. Financial incentives are available to owners when the efficiency of the new building exceeds minimum thresholds, generally 10% better than California's Title 24 standards. The maximum owner incentive is $150,000 per free-standing building or individual meter. Design team incentives are offered when a building design saves at least 15%. The maximum design team incentive per project is $50,000.
Target Group:	Nonresidential new construction or major renovation projects
Format:	Open year round
URL:	http://www.savingsbydesign.com/

Indiana – Industrial Programs

Description:	The Energy Policy Division of the Indiana Department of Commerce operates two industrial programs. The Industrial Energy Efficiency Fund (IEEF) is a zero-interest loan program (up to $250,000) to help Indiana manufacturers increase the energy efficiency of manufacturing processes. The fund is used to replace or convert existing equipment, or to purchase new equipment as part of a process/plant expansion that will lower energy use. The Distributed Generation Grant Program (DGGP) offers grants of up to $30,000 or up to 30% of eligible costs for distributed generation with an efficiency over 50% to install and study distributed generation technologies such as fuel cells, micro turbines, co-generation, combined heat & power and renewable energy sources. Other programs support can support companies in the use of biomass for energy, research or building efficiency.
Target Group:	Any industry located in Indiana
Format:	Application year-round for IEEF and in direct contact for DGGP
Contact:	Energy Policy Division, (317) 232-8970
URL:	http://www.iedc.in.gov/Grants/index.asp

Iowa – Alternate Energy Revolving Loan Program

Description:	The Alternate Energy Revolving Loan Program (AERLP) was created to promote the development of renewable energy production facilities in the state.
Target Group:	Any potential user of renewable energy
Format:	Proposals under $50,000 are accepted year-round. Larger proposals are accepted on a quarterly basis.
Contact:	Iowa Energy Center, (515) 294-3832
URL:	http://www.energy.iastate.edu/funding/aerlp-index.html

New York – Industry Research and Development Programs

Description:	The New York State Energy Research & Development Agency (NYSERDA) operates various financial assistance programs for New York businesses. Different programs focus on specific topics, including process technology, combined heat and power, peak load reduction and control systems.
Target Group:	Industries located in New York
Format:	Solicitation
Contact:	NYSERDA, (866) NYSERDA
URL:	http://www.nyserda.org/programs/Commercial_Industrial/default.asp?i=2

Wisconsin – Focus on Energy

Description:	Energy advisors offer free services to identify and evaluate energy-saving opportunities, recommend energy efficiency actions, develop an energy management plan for business; and integrate elements from national and state programs. It can also provide training.
Target Group:	Industries in Wisconsin
Format:	Open year round
Contact:	Wisconsin Department of Administration, (800) 762-7077
URL:	http://focusonenergy.com/portal.jsp?pageId=4