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Improving Energy Efficiency in Pharmaceutical Manufacturing Operations —
Part I: Motors, Drives and Compressed Air Systems

In Part I of this two-part series, we focus on efficient use of motors, drives and pumps, both for process equipment and compressed air systems.

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Pharmaceutical manufacturing plants in the U.S. spend nearly $1 billion each year for the fuel and electricity they need to keep their facilities running (Figure 1, below). That total that can increase dramatically when fuel supplies tighten and oil prices rise, as they did last year.

Improving energy efficiency should be a strategic goal for any plant manager or manufacturing professional working in the drug industry today. Not only can energy efficiency reduce overall manufacturing costs, it usually reduces environmental emissions, establishing a strong foundation for a corporate greenhouse-gas-management program.

For most pharmaceutical manufacturing plants, Heating, Ventilation and Air Conditioning (HVAC) is typically the largest consumer of energy, as shown in Table 1 below.

This two-part series will examine energy use within pharmaceutical facilities, summarize best practices and examine potential savings and return on investment. In this first article, we will focus on efficient use of motors, drives and pumps, both for process equipment and compressed air systems. Part 2, to be published in May, will focus on overall HVAC systems, building management and boilers.

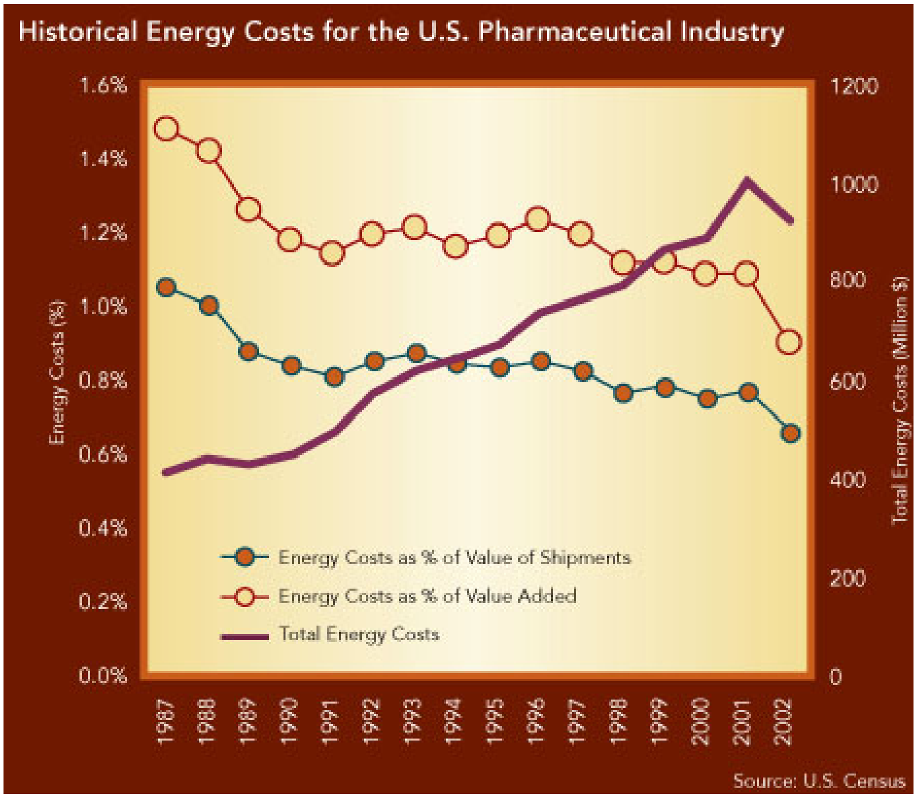
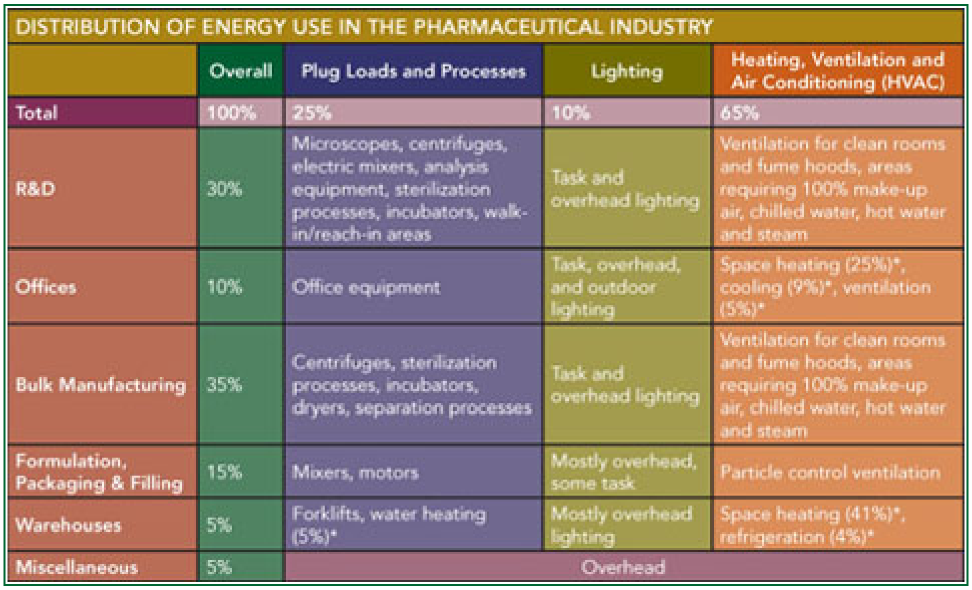


Figure 1. U.S. drug manufacturing plants spend nearly $1 billion each year for the fuel and electricity needed to run their facilities.

Research in this article was first published last September, in an extensive report developed by Lawrence Berkeley National Laboratories for the Energy Star Pharmaceutical Focus. Established in January 2005, this group of pharmaceutical industry corporate energy managers is working to develop resources and tools to foster improved energy efficiency within the industry.

The Environmental Protection Agency (EPA) is also working with Argonne National Laboratory to develop an energy performance benchmarking tool for pharmaceutical plants (see "Will Pharma Wear the Energy Star?"). For more information, please visit www.energystar.gov.



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	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	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		

Table 1. For most pharmaceutical manufacturing plants, HVAC is typically the largest consumer of energy.

1 A "systems approach" to motors and drives

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 to move and operate filling and finishing equipment.

In order to prioritize areas for improvement, it is best to take a "systems approach" and look at the entire motor system, including pumps, compressors, motors and fans, instead of examining each component individually. The following steps should be taken:

1. Locate and identify all motor applications (e.g., pumps, fans) in the facility;
2. Document their conditions and specifications;
3. Compare your requirements vs. the actual use of the system to determine the energy consumption rate; this will help determine whether the motors have been properly sized;
4. Collect information on potential upgrades or updates to the motor systems, including implementation costs and potential annual savings;

5. If you do elect to upgrade or update any equipment, monitor its performance over time to determine actual costs savings [1].

Other essential issues for energy efficient operation include:

- **Maintenance.** This can save from 2% to 30% of total motor system energy use [2].

  Preventive measures consider electrical conditions and load, minimize voltage imbalance and include motor ventilation, alignment and lubrication.

  Predictive measures observe ongoing temperature, vibration and other operating data to determine when to overhaul or replace a motor before it fails.

- **Sizing.** Ensuring that motors are properly sized, and that oversized motors are replaced, can save, on average, 1.2% of total motor system electricity consumption [3]. Generally, whenever peak loads can be reduced, so can motor size.

- **Belt drive replacement.** Roughly 4% of pumps have V-belt drives, many of which can be replaced with direct couplings to save energy [4]. Savings associated with V-belt replacement are about 4% of total motor system electricity consumption, and costs are estimated at $0.10/kWh-saved with payback within two years.

- **Rewinding vs. replacement.** Replacing an old motor with a high-efficiency motor is often a better choice than rewinding a motor. Currently, there are no quality or efficiency standards for rewinding, and motor efficiency typically decreases from 2% to 25% after rewinding.

When considering whether to rewind a motor or to replace it with a higher-efficiency model, consider the following rules of thumb:

1. Never rewind a motor damaged by excessive heat;
2. Replace motors that are less than 100 hp and more than 15 years old;
3. Replace any motors that have previously been rewound [5].

High-efficiency motors, meeting or exceeding performance criteria published by the National Electrical Manufacturers Association (NEMA), reduce energy losses through improved design, better materials, tighter tolerances and improved manufacturing techniques.

2 Making the case for replacement

Replacing an old, poorly functioning motor with a high-efficiency one is easily justified, since payback is usually accomplished in less than a year [6]. Twenty-three case studies of high-efficiency motor installations in the U.S. pharmaceutical industry showed an average payback period of less than three years [7].

Justifying replacement may be more difficult when an old motor still performs adequately, but, even in these cases, replacement can save money, especially for motors that run for long hours at high loads. One study [8] showed a payback period of less than 15 months for 50 horsepower (hp) motors.

3M conducted an in-house motor system performance optimization project at a facility housing pilot plants, mechanical and electrical maintenance shops, laboratories and support functions. After evaluating all electric motors larger than 1.5 hp in the building, the company identified 50 older, standard-efficiency motors that ran for more than 6,000 hours per year. Twenty-eight of these motors were replaced with energy-efficient motors.

The company expected to see a 2% to 5% improvement in energy efficiency for each motor that was replaced. 3M also took other steps such as changing impellers or sheaves to reduce the driven load, downsizing motors to better match system requirements, and repairing and cleaning components to reduce efficiency losses. Payback took 3.1 years [9].

Adjustable speed drives (ASDs) better match speed to load requirements, offering substantial savings in a variety of applications [10]. Typical savings range from 7% to 60%. Four case studies in the U.S. pharmaceutical industry have demonstrated an average payback period for ASDs of less than two years [11]. These four case studies included the installation of ASDs on cooling tower fans, ventilation equipment and a dust collector motor. Genentech has installed ASDs on variable air volume (VAV) air handlers in its Vacaville, Calif. facility, saving about $23,000 per year.

3 Compressed air: the money pit

Compressed air is required for many pharmaceutical manufacturing applications, including equipment operation, vacuum cleaning, spray systems, ambient and instrument air in hazardous areas. In pharmaceutical facilities, compressed air often comes in contact with products, such as in spray coating operations or in packaging, so it is often filtered to meet strict contamination control standards.

Despite its importance, compressed air is one of the least energy-efficient applications in any drug manufacturing plant. Efficiency of compressed air systems is only around 10%, so compressed air should be used sparingly. When used, it should be monitored, and weighed against potential alternatives.

Techniques for reducing energy consumption in compressed air systems aren't very expensive, and savings can range from 20% to 50% or more of total system electricity consumption [12]. Below are some issues to consider where compressed air systems are concerned.

Buying additional compressors should only be considered after a complete system evaluation. Energy efficiency can often be improved without adding compressors (visit www.compressedairchallenge.org for tips on selecting the right integrated service provider, as well as guidelines defining walk-through evaluations, system assessments and fully instrumented system audits).

Maintenance is essential to improving efficiency. The following guidelines should apply:

- **Keep the compressor and intercooling surfaces clean.** Blocked filters increase pressure drop, and more frequent filter changing can reduce annual energy consumption by 2%. Seek filters with just a 1 psig pressure drop over 10 years. The payback for filter cleaning is usually under two years [13]. Fixing improperly operating filters will also prevent contaminants from entering into equipment, which can cause premature wear.

- **Keep motors properly lubricated and cleaned.** Compressor lubricant should be changed every two to 18 months and checked to make sure it is at the proper level.This will also reduce corrosion and degradation of the system.

- **Inspect fans and water pumps** for peak performance.
- **Inspect drain traps periodically** to ensure that they are not stuck in either the open or closed position and that they are clean. Some users leave automatic condensate traps partially open at all times to allow for constant draining. This should never be done, as it wastes a substantial amount of energy. Instead, install simple pressure-driven valves. Inspecting and maintaining drains typically has a payback of less than 2 years [13] .
- **Maintain the coolers on the compressor** to ensure that the dryer gets the lowest possible inlet temperature [13].
- **If using compressors with belts, check belts for wear and adjust them.** A good rule of thumb is to adjust them every 400 hours of operation.
- **Replace air lubricant separators according to specifications or sooner.** Rotary screw compressors generally start with their air lubricant separators having a 2-3 psi pressure drop at full load. Once this number increases to 10 psid, change the separator [14].
- **Check water-cooling systems for water quality (pH and total dissolved solids), flow and temperature.** Clean and replace filters and heat exchangers per manufacturer's specifications.
- **Minimize leaks** (see also the "Leak Reduction" section below).
- **Specify pressure regulators that close when failing.**
- **Check all applications requiring compressed air for excessive pressure, duration or volume.** They should be regulated either by production line sectioning or by pressure regulators on the equipment itself. Equipment that does not have to run at maximum system pressure should use a quality pressure regulator that will not drift. Payback for this step is less than six months [15].

Monitoring can save significant energy and cost in compressed air systems. The following tips can help:

- **Install pressure gauges** on each receiver or main branch line and differential gauges across dryers and filters.
- **Use temperature gauges** across the compressor and its cooling system to detect fouling and blockages.
- **Measure the quantity of air used** with flow meters.
- **Monitor the effectiveness of air dryers** with dew-point temperature gauges.
- **Place kilowatt-hour (kWh) meters and hours-run meters on the compressor drive.**

Compressed air distribution systems should be checked when equipment has been reconfigured to be sure that air isn't flowing to unused equipment or obsolete parts of the compressed air distribution system. Compressed air use should also be checked outside of normal production hours.

In addition, it is important to check for flow restrictions of any type within the system, since they will require higher than necessary operating pressures. The pressure rise that results from resistance to flow increases the drive energy on the compressor by 1% of connected power for every 2 psig of differential.

- **Leak reduction.** Air leaks are a major energy drain, but they also can damage equipment. A poorly maintained compressed air system will likely have a leak rate equal to 20% to 50% of total capacity. Leak maintenance can reduce this number to less than 10%. Fixing leaks pays off, reducing annual energy consumption by 20% [16].

  The magnitude of the energy loss varies with the size of the hole in the pipes or equipment. A compressor operating 2,500 hours per year at 6 bar (87 psi) with a leak diameter of 0.02 in. (½ mm) will lose 250 kWh per year; 0.04 in. (1 mm) will lose 1,100 kWh per year; 0.08 in. (2 mm) will lose 4,500 kWh per year; and 0.16 in. (4 mm) will lose 11,250 kWh per year [17]. Payback takes less than two months [18]. The best way to detect leaks is to use an ultrasonic acoustic detector.

- **Turning off unnecessary compressed air, using a solenoid valve.**

- **Modifying rather than increasing operating pressure.** For individual applications that require a higher pressure, instead of raising the operating pressure of the whole system, consider special equipment modifications, e.g., a booster, increasing a cylinder bore, changing gear ratios or changing operation to off-peak hours.

- **Considered alternatives to compressed air, such as:**

    1. air motors only for positive displacement;
    2. air conditioning fans instead of compressed air vortex tubes in cooling electrical cabinets;
    3. vacuum pumps instead of venturi methods for flowing high-pressure air past an orifice;
    4. blowers for cooling, aspirating, agitating, mixing or package inflating;
    5. blowers or vacuum pump systems for cleaning parts or removing debris;
    6. electric actuators or hydraulics for moving parts;
    7. low-pressure air for blowguns, air lances and agitation;
    8. motors for tools or actuators, except in situations where precision and safety are paramount.

Payback for replacing compressed air with other options takes an average of 11 months.

- **Better load management.**

    1. **Avoid partial load operation.** For example, unloaded rotary screw compressors still consume 15-35% of full-load power while delivering no useful work. Centrifugal compressors are cost-effective when operated at high loads.
    2. **Use air receivers 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 on-line compressors may be reduced.

3. **Replace single-stage compressors with two-stage compressors.** This typically provides a payback period of two years or less. Multi-stage compressors theoretically operate more efficiently than single-stage compressors because they cool the air between stages, reducing the volume and work required to compress the air.

4. **Use multiple smaller compressors instead of one large compressor.** Large compressors consume more electricity when they are unloaded than do multiple smaller compressors with similar overall capacity. Optimal sizing pays for itself in about 1.2 years.

- **Minimizing pressure drop.** 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 that the air travels through the distribution system should be minimized. Audit results found that the payback period is typically shorter than 3 months for this measure.

- **Reducing inlet air temperature.** 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 5°F (3°C) will save 1% compressor energy.

- **Maximizing the allowable pressure dew point at air intake.** Choose a dryer that has the maximum allowable pressure dew point and best efficiency. A rule of thumb is that desiccant dryers consume 7-14% of the total energy of a compressor, whereas refrigerated dryers consume 1-2% of the total energy of a compressor.

- **Controls.** Sophisticated controls can save 12% per year. Options include start/stop, load/unload, throttling, multi-step, variable speed and network.

- **Properly sized regulators —** optimally, those that close when they fail.

- **Properly sized pipe diameters.** Increasing diameters can reduce energy consumption to 3%.

- **Heat recovery for water preheating.** Up to 90% of the electrical energy used by an industrial air compressor is converted into heat. In many cases, a heat recovery unit can recover 50-90% of the available thermal energy. It has been estimated that approximately 50,000 btu/hour of energy is available for each 100 cfm of compressor capacity [19]. Payback periods are typically less than 1 year.

- **Natural gas engine-driven air compressors.** Gas engine-driven air compressors can replace electric compressors. They are more expensive 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 compressors need more maintenance, have a shorter useful life and have a greater likelihood of downtime.

4 Pumps

Pumping systems account for about 25% of the electricity used in U.S. manufacturing plants, and pumping coolants is an energy-intensive pharmaceutical application. Studies have shown that over 20% of the energy consumed by pumping systems could be saved through changes to equipment and/or control systems.

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. In contrast, energy costs make up about 95% of the lifetime costs of the pump. Maintenance costs comprise the remaining 2.5% [20]. Hence, the initial choice of a pump system, consisting of a pump, a drive motor, piping networks and system controls such as ASDs or throttles should be highly dependent on energy cost considerations rather than on initial costs.

The energy-efficiency measures described below apply to all pump applications.

- **Maintenance.** Proper pump system maintenance includes the following:

1. Replacement of worn impellers, especially in caustic or semi-solid applications.

2. Bearing inspection and repair.

3. Bearing lubrication replacement, on an annual or semiannual basis.

4. Inspection and replacement of packing seals. Allowable leakage from packing seals is usually between 2 and 60 drops per minute.

5. Inspection and replacement of mechanical seals. Allowable leakage is typically 1 to 4 drops per minute.

6. Wear ring and impeller replacement. Pump efficiency degrades 1-6 points for impellers less than the maximum diameter and with increased wear ring clearances.

7. Pump/motor alignment check.

Better pump maintenance saves between 2% and 7% of pumping electricity, with paybacks within a year.

- **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. Bypass loops and other unnecessary flows should be eliminated. Each of these steps can save 5-10% of pump system electricity consumption.

- **Controls.** The objective of any control strategy is to shut off unneeded pumps or, alternatively, to reduce pump load until needed.

- **Replacing older pumps with high-efficiency pumps.** According to inventory data, 16% of pumps used in industry are more than 20 years old. A pump's efficiency may degrade by 10-25% in its lifetime. 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%..

- **Properly sized pumps.** Optimal sizing can save, on average, 15-25% of the electricity consumption of a pumping system.

Paybacks for implementing these solutions are typically less than 1 year.

- **Multiple pumps for variable loads.** This is the most cost-effective and energy-efficient solution for varying loads.
- **Impeller trimming.** If a large differential pressure exists at the operating rate of flow (indicating excessive flow), the impeller diameter can be trimmed so that the pump does not develop as much head. Impeller trimming can save up to 75% of electricity consumption.

Part II: HVAC, Boilers and Cogeneration

Significant potential exists for improving energy efficiency in the U.S. pharmaceutical industry, and a focused, strategic approach can allow any organization to identify opportunities and implement efficiency measures and practices. This article, the second in a two-part series, summarizes strategies for reducing pharmaceutical facility energy costs.

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Whereas Part I of this article ("Improving Energy Efficiency in Pharmaceutical Manufacturing Operations — Part I: Motors, Drives and Compressed Air Systems", Pharmaceutical Manufacturing, *Feb. 2006) focused on motors, drives and compressed air systems, Part II will review, briefly, potential improvements in heating, ventilation and air conditioning (HVAC) systems, overall building management and boilers. Research in this article was first published last September, in an extensive report developed by the Energy Analysis Department at Lawrence Berkeley National Laboratories for the Environmental Protection Agency's Energy Star Pharmaceutical Focus. The 90-page guide, "Energy Efficiency Improvement and Cost Saving Opportunities for the Pharmaceutical Industry," is available in pdf format at www.energystar.gov.*

The U.S. pharmaceutical industry spent nearly $900 million on energy in 2002. As energy costs increase, more companies are looking into energy efficiency measures *(to view this table — a one-page PDF — click the Download Now button at the end of this article).* Considered individually, each measure may offer small savings, but combined they add up to significant savings and short payback periods.

5 HVAC

First, let’s consider HVAC systems, which consist of dampers, supply and exhaust fans, filters, humidifiers, dehumidifiers, heating and cooling coils, ducts, and various sensors [1]. HVAC systems in manufacturing portions of facilities are closely supervised by the FDA and must meet other global regulatory standards, so energy efficiency measures that affect the work environment must conform to current Good Manufacturing Practices (cGMP). Although cGMP allows for new techniques, the reasons for using them must be explained — the additional time required, and the risks associated with a delay in approval of building plans, may have led some drug companies to stick with less energy-efficient designs.

Nevertheless, investing in newer technology frequently pays off. At its plant in Rzeszow, Poland, for example, Novartis installed microprocessor controls on its HVAC system that could be programmed to better balance plant heating based on outside temperatures, and reduce heating loads on the weekends. The company expects this new system to reduce overall heat energy consumption by 10% [2].

There are many energy efficiency measures that can be applied to HVAC systems; some significant opportunities are discussed below.

Non-production hours set-back temperatures. Setting back building temperatures (that is, turning 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.

At Merck’s Rahway, N.J. 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 square feet of floor space. The energy savings from 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 [3].

Adjustable speed drives (ASDs). 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. Genentech installed ASDs on variable air volume air handlers in its Vacaville, Calif. facility, leading to significant reductions in energy consumption and expected annual savings of around $23,000 per year [4].

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.

In 2004, Merck installed a glycol run-around loop system to recover heat from HVAC exhaust air at a 37,000-square-foot laboratory building in Rahway. After installation, the building could pre-heat and pre-cool up to 120,000 cubic feet per minute (cfm) of outside air with recovered energy. The savings associated with this measure amounted to roughly 265 MBtu per year, which led to avoided CO2 emissions of over 30 tons per year [3].

Improving HVAC chiller efficiency. 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 installing separate high-temperature chillers for process cooling [5].

Sizing chillers to better balance chiller load with demand is also an important energy efficiency strategy. At Genentech's facility in Vacaville, 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 additional 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 [4].

6 Cleanroom HVAC

A recent study found that HVAC systems accounted for 36-67% of cleanroom energy consumption [6]. Another recent study [7] estimated the following energy distribution for cleanroom operation: 56% for cooling, 36% for heating, 5% for fans, and 3% for pumps.

The following measures can improve energy efficiency in cleanrooms:

Reduce recirculation air charge rates.

Improve 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 [8].

Use 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.

Reduce 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.

7 Boilers

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. The following measures can improve energy efficiency in boilers:

Reduce 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 [9].

Reduce 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. 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 [10].

Properly size 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 [11].

Properly insulate boiler.

Perform regular maintenance. A simple maintenance program to ensure that all components of a boiler are operating at peak performance can result in substantial savings. On average, the energy savings associated with improved boiler maintenance are estimated at 10% [10].

Reuse condensate. 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. A Pfizer plant in Groton, Conn., upgraded their condensate recovery system and realized a 9% reduction in electricity consumption, and an 8% reduction in water consumption and wastewater discharge [12]. As a result, Pfizer saved roughly $175,000 per year through avoided oil, gas, and water purchases.

8 Cogeneration

The use of cogeneration in the U.S. pharmaceutical industry is still limited. Currently, most large-scale CHP (combined heat and power) systems use steam turbines. 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.

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.

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.

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, Calif. 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 and allow the facility to operate independent of the state electrical grid, if needed. It will also reduce emission of more than 3 million pounds of CO_2 per year.

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