
Energy Savings in MEP Systems - Energy Systems

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GREENING FEDERAL FACILITIES

An Energy, Environmental, and Economic Resource Guide for Federal Facility Managers and Designers

Part V

ENERGY SYSTEMS

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The Federal Government is the largest single user of energy in the United States and purchases \$10–20 billion in energy-related products each year. With ownership of more than 500,000 buildings, including 422,000 housing structures, the Federal Government has a tremendous interest in energy efficiency in buildings. The Energy Policy Act of 1992 and Executive Order 13123 set goals for energy reduction and provide some guidelines for implementing conservation measures. Annual energy use in Federal buildings has dropped from 140,000 Btu/sq ft (1,600 MJ/m²) in 1985 to 116,000 Btu/sq ft (1,300 MJ/m²) in 1997. To meet the Executive Order 13123 requirement, annual energy use must drop to 90,800 Btu/sq ft (1,000 MJ/m²) by 2010. FEMP provides information on technologies that have been proven in field testing or recommended by reliable sources, such as the DOE national laboratories.

Opportunities

The time for planning, evaluating, and implementing is now! Facility managers should first implement energy- and demand-reducing measures in their operations and then look for opportunities to cost-effectively replace conventional technologies with ones using renewable energy sources.

Facility managers should also set goals for their operations that follow Federal mandates. Executive Order 13123 requires an energy reduction in Federal buildings of 30% by 2005 and 35% by 2010, relative to 1985. Industrial and laboratory facilities are required to reduce energy consumption by 20% by 2005 and 25% by 2010, relative to 1990. Executive Order 13123 further states that agencies shall use life-cycle cost analysis in making decisions about their investments in products, services, construction, and other projects to lower the Federal government's costs and to reduce energy consumption. When energy-consuming equipment needs replacement, guidance for purchasing products that meet or exceed Executive Order 13123 procurement goals is available through FEMP's Product Energy Efficiency Recommendations series.

Technical Information

The *Energy Systems* section of this guide describes systems that provide key opportunities for energy savings. The following are some of these opportunities:

Integrated design is a process whereby the various disciplines involved in design—architect, mechanical engineer, electrical engineer, interior design professional, etc.—work together to come up with design solutions that maximize performance, energy conservation, and environmental benefits. Integrated design is an important aspect of energy conservation and equipment selection because decisions made in one area (lighting, for example) will affect others (such as chiller sizing). Refer back to *Section 4.1 – Integrated Building Design* for an overview.

HVAC system improvements offer tremendous potential for energy savings in most facilities. Opportunities include replacing older equipment with more efficient products, improving controls, upgrading maintenance programs, and retrofitting existing equipment to operate more efficiently. Central plants contain many interrelated components, and upgrading them takes careful planning, professional design assistance, and careful implementation. This guide covers chillers, boilers, air distribution systems, and other HVAC technologies.

Water heating is a major energy user in facilities with kitchens and laundries. Beyond reducing the use of hot water, various heat recovery and solar technologies can also help reduce operating costs.

Lighting. More than \$250 million could be saved annually if all Federal facilities upgraded to energy-efficient lighting. Light energy savings of up to 40% can be achieved in interior applications by replacing lamps and ballasts. Savings of well over 50% are possible by designing and implementing an integrated approach to lighting that includes daylighting, task lighting, and sophisticated controls.

Office equipment is becoming an ever greater proportion of building loads. “Green” appliances that feature automatic power shutdown and more efficient electronics can help reduce energy consumption.

Energy Management and Control Systems (EMCSs) are critical in avoiding energy waste and monitoring energy consumption. Control technology should be applied intelligently for each situation, and an optimized mix of local and central control should be used.

Electric motor systems that operate around the clock (or nearly so) consume many times their purchase price in electricity each year. This makes inefficient, large-horsepower motors excellent targets for replacement. If the driven load operates at reduced speed a majority of the time, installing electronic motor controls could reduce both energy consumption and operating costs.

Electrical power systems can be made more efficient through (1) maintenance practices focused on identifying potential trouble areas, such as loose electrical connections; and (2) selection of efficient electrical equipment, such as transformers. There may also be opportunities to use renewable power-generation equipment.

Making It Happen

Carrying out energy efficiency improvements in Federal buildings is not simply about energy technologies and systems, it is also about financing and budgets. Here are a few financing strategies that can be applicable to Federal buildings. Also refer to *Section 2.4 – Alternative Financing*.

Energy Savings Performance Contracts provide Federal agencies with a means of increasing their investment in energy-saving technologies. Because appropriated funds are shrinking for many agencies, ESPCs enable them to secure financing from energy service contractors, or ESCOs, to identify and implement energy conservation measures. In effect, agencies can defer the initial costs of equipment and pay for the equipment through utility-bill savings. FEMP assists Federal agencies with ESPCs.

Super ESPCs are a facilitated form of ESPC. They are regional agreements in which delivery orders are placed against a contract with selected ESCOs. A Super ESPC allows individual facilities to negotiate contracts directly with certain competitively selected companies, greatly reducing the complexity of the ESPC process.

Basic Ordering Agreements (BOAs) are written understandings negotiated between GSA and a utility or other business that set contract guidelines for energy-consuming products and services. For example, the GSA Chet Holifield Federal Center in Laguna Niguel, California, contracted with its electric utility for thermal energy storage, energy-efficient chillers, variable-frequency drives, efficient motors, and lighting system retrofits. The contractor invested \$3,800,000,



Source: Farallon National Wildlife Refuge

The U.S. Fish and Wildlife service needed a cleaner, quieter power source for the Farallon National Wildlife Refuge, 30 miles (48 km) west of San Francisco. Applied Power designed a 9.1-kW hybrid photovoltaic system to withstand the extremely corrosive island environment. Before this installation, the staff operated extremely loud, expensive diesel generators during daylight hours only.

and the government's share of the savings is \$1,400,000 over 14 years. The GSA retains the equipment after the contract term. One prominent BOA specifying energy-efficient chillers for Federal procurement has been developed between GSA and five major chiller manufacturers in the United States. Other BOAs are being developed and will be available soon.

References

Architect's and Engineer's Guide to Energy Conservation in Existing Buildings (DOE/RL/018-30P-H4), U.S. Department of Energy, Washington, DC, 1990.

Technology Atlas Series, E Source, Inc., Boulder, CO, 1996-97; (303) 440-8500; www.esource.com.

Contacts

To access FEMP's *Product Energy-Efficient Recommendations* series or obtain more information on financing alternatives, visit the FEMP Web site at www.eren.doe.gov/femp or call the FEMP Help Desk at (800) DOE-EREC (363-3732).

Heating, ventilating, and air-conditioning systems can be the largest energy consumers in Federal buildings. HVAC systems provide heating, cooling, humidity control, filtration, fresh air makeup, building pressure control, and comfort control—all requiring minimal interaction between the occupants and the system. Properly designed, installed, and maintained HVAC systems are efficient, provide comfort to the occupants, and inhibit the growth of molds and fungi. Well-designed, energy-efficient HVAC systems are essential in Federal buildings and contribute to employee productivity. Boilers, air distribution systems, chillers, absorption cooling systems, desiccant dehumidification, ground-source heat pumps, and new HVAC technologies are covered in the sections that follow.

Opportunities

Consider upgrading or replacing existing HVAC systems with more efficient ones if current equipment is old and inefficient; if loads have changed as a result of other conservation measures or changes in building occupancy; if control is poor; if implementing new ventilation standards has caused capacity problems; or if moisture or other indoor air quality problems exist. Be sure to have a plan in place for equipment change-out and failure. The phase-out of CFCs is another factor encouraging chiller replacement. In all these cases, an *integrated* approach should be utilized that looks at the entire cooling system and the entire building to take advantage of synergies that allow for *downsizing*, as well as boosting the efficiency of, a replacement chiller.

Technical Information

Strategies for reducing HVAC operating costs in large facilities include the following:

Reduce HVAC loads. By reducing building loads, less heating and cooling energy is expended. Load reduction measures include adding insulation; shading harsh wind and sun exposures with trees, shade screens, awnings, or window treatments and minimizing the use of heat-producing equipment, such as office equipment and computers; daylighting; controlling interior lighting; and capturing heat from exhaust air. See *Part 4* of this guide for more on building design issues.

Incorporate building automation/control systems. These systems can be added or upgraded to improve the overall performance of the building, including the HVAC equipment. Perhaps the simplest measure and the first to be considered should be to ensure that HVAC systems are in “setback” mode during un-

occupied periods. Existing control systems will often accommodate this very simple measure. Sections 5.6, 5.6.1, and 5.4.4 (for lighting) address energy controls in more detail.

Optimize for part-load conditions. Buildings usually operate under conditions in which the full heating or cooling capacity is not required. Therefore, significant improvements in annual efficiency will result from giving special consideration to part-load conditions. Staging multiple chillers or boilers to meet varying demand greatly improves efficiencies at low and moderate building loads. Pairing *different-sized* chillers and boilers in parallel offers greater flexibility in output while maintaining top performance. Units should be staged with microprocessor controls to optimize system performance.

Isolate off-line chillers and boilers. In parallel systems, off-line equipment should be isolated from cooling towers and distribution loops. With reduced pumping needs, circulation pumps can be shut off or modulated with variable-speed drives.

Use economizers. In climates with seasons having moderate temperatures and humidity, adding air- and water-side economizer capabilities can be cost-effective. When ambient conditions permit, outside air provides space conditioning without the use of the cooling plant. To prevent the inappropriate introduction of outside air, careful attention must be given to economizer logic, controls, and maintenance. With a water-side economizer, cooling is provided by the cooling tower without the use of the chiller.

Remember that ventilation systems have a tremendous impact on energy use because of the high costs associated with heating or cooling outside air. Buildings should be ventilated according to ASHRAE Standard 62. The outside air requirements—15 to 20 cfm (7.1–9.5 L/s) per person in most commercial buildings—of Standard 62’s most recent version (62-1989) do not apply to buildings constructed before it was published, although for new additions of 25% or more, this “grandfathering” is not permitted by the major building codes. The indoor air quality benefits of complying with ASHRAE 62-1989, such as higher productivity and decreased sick leave, may often make the added expense worthwhile, even when not required by law.

Upgrade cooling towers. Large savings are possible when cooling towers are retrofitted with new fill, efficient transmissions, high-efficiency motors, and variable-frequency drives. Good water chemistry is needed to minimize the use of environmentally hazardous chemical biocides. Ozone treatments also may be useful.



Chillers have changed dramatically in recent years. Today's models are far better for the environment than older products.

Photo: McQuay Air Conditioning

Interconnect mechanical rooms for greater modularity and redundancy. This increases effective capacity while improving part-load efficiency.

IMPORTANCE OF MAINTENANCE

Proper maintenance helps prevent loss of HVAC air balance (return, supply, and outdoor air); indoor air quality problems; improper refrigerant charge; fouling of evaporator coils by dust and debris; poor water quality in cooling towers; and water damage from condensate.

Provide a monitoring and diagnostic capability. An important part of maintaining the rated efficiency of equipment and optimal performance of HVAC systems is understanding how they are functioning. Incorporate systems to track performance and identify problems quickly when they occur.

Ensure that air handlers are maintained. To achieve better indoor air quality and reduce operating costs, steam-clean evaporator coils and air handlers at a minimum three-year rotation. Also service filters frequently.

Service the ventilation system. A good balance report is required. Airflows can then be periodically checked. Periodically lubricate dampers and check their operation by exercising the controls.

Prevent or repair air distribution system leakage. In residential and small commercial buildings, air duct leakage can be a huge energy waster. Leaks can also cause comfort and air quality problems. Check ventilation rates after duct repair to ensure that

ASHRAE standards are met and that desired pressure relationships are maintained.

Eliminate or upgrade inefficient steam systems. Leaks are a common problem with older central steam distribution systems. Regularly inspect for evidence of leaks; repair problems as they occur or upgrade the system.

Check for improper refrigerant charge. Refrigerant-based HVAC systems require precise levels of refrigerant to operate at peak capacity and efficiency, and to most effectively control interior humidity in moist climates. Loss of refrigerant charge not only wastes money but also damages the environment—most refrigerants deplete stratospheric ozone. Inspect for leaks and promptly fix problems. Consider replacing older equipment with new, more efficient, ozone-safe systems.

Provide or consider ease of maintenance when making any HVAC system modifications or equipment purchases. Make sure that access to filters (for cleaning or replacement), ducts (for inspection and cleaning), controls, and other system components remains easy. Label components that will need servicing, and post any necessary inspection and maintenance instructions clearly for maintenance personnel.

References

ASHRAE Standard 62 (ventilation), *Standard 90.1* (energy performance), others; American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, GA; www.ashrae.org.

A Design Guide for Energy-Efficient Research Laboratories, Lawrence Berkeley National Laboratory; available online (also downloadable) at ateam.lbl.gov/Design-Guide.

Space Heating Technology Atlas (1996) and *Commercial Space Cooling and Air Handling Technology Atlas* (1997), E Source, Inc., Boulder, CO; (303) 440-8500; www.esource.com.

Contacts

HVAC retrofits and maintenance opportunities are thoroughly covered in the FEMP-sponsored “Trained Energy Manager” course. Contact the FEMP Help Desk at (800) DOE-EREC (363-3732) for course information.

Information about the Laboratories for the 21st Century project is online at www.epa.gov/labs21century/.

For written material and software to assist with evaluating HVAC systems, contact the EPA ENERGY STAR® Building Hotline, (202) 775-6650; www.energystar.gov.

5.2.1 Boilers

Most medium-to-large facilities use boilers to generate hot water or steam for space heating, domestic water heating, food preparation, and industrial processes. For boilers to run at peak efficiency, operators must attend to boiler staging, water chemistry, pumping and boiler controls, boiler and pipe insulation, fuel-air mixtures, burn-to-load ratio, and stack temperatures.

Opportunities

Every effort should be made to upgrade boiler systems to peak efficiency in order to reduce operating costs and environmental impacts. When replacing old equipment or installing new equipment:

- Consider the advantages of multiple boiler systems, which are more efficient than single boilers, especially under part-load conditions.
- Consider solar-assisted systems and biomass-fired boilers as alternatives to conventional boiler systems.
- Consider opportunities for cogeneration (combined heat and power), including the use of fuel cells and microturbines as the heat source.

Technical Information

Note recent trends in boiler systems, which include installing multiple small boiler units, decentralizing systems, and installing direct digital control (DDC) systems, including temperature reset strategies. Because these systems capture the latent heat of vaporization from combustion water vapor, flue-gas temperatures are low enough to vent the exhaust through polyvinyl chloride (PVC) pipes; PVC resists the corrosive action of flue-gas condensate.

Replace inefficient boilers. In newer units, more fuel energy goes into creating heat, so both stack temperatures and excess oxygen are lower. Estimate efficiencies of existing units by measuring excess air, flue and boiler room temperatures, and percent of flue-gas oxygen and carbon dioxide. Some utilities will provide this service free of charge. Boilers are available that have efficiencies greater than 90%.

Decentralize systems. Several smaller units strategically located around a large facility reduce distribution losses and offer flexibility in meeting the demands of differing schedules, as well as steam pressure and heating requirements. Estimate standby losses by monitoring fuel consumption during no-load periods.

Downsize. Strive to lower overall heating demands through prudent application of energy conservation measures, such as increased building insulation and improved glazings. Smaller boilers may be staged to meet loads less expensively than large central plants. Many new units are designed to ease retrofit by fitting through standard doorways.

Modernize boiler controls. Direct digital controls consist of computers, sensors, and software that provide the real-time data needed to maximize boiler system efficiency. They allow logic-intense control functions to be carried out, such as temperature reset, optimizing fuel/air mixture based on continuous flue-gas sampling, managing combustion, controlling feedwater and drum levels, and controlling steam header pressure.

Install an economizer. Install a heat exchanger in the flue to preheat the boiler feedwater. Efficiency increases about 1% for every 10°F (5.5°C) increase in feedwater temperature. If you are considering an economizer, ensure (1) that the stack temperature remains higher than the acid dew point in order to prevent flue damage, and (2) that excess flue temperature is due to insufficient heat transfer surfaces in the boiler rather than scaling or other maintenance problems.

Install an oxygen trim system. To optimize the fuel/air ratio, these systems monitor excess oxygen in the flue gas and modulate air intake to the burners accordingly.

Reduce excess air to boiler combustion. The common practice of using 50–100% excess air decreases efficiency by 5%. Work with the manufacturer to determine the appropriate fuel/air mixture.

Install air preheaters that deliver warm air to the boiler air inlets through ducts. The source of warm air can be the boiler room ceiling, solar panels, or solar-preheat walls. Managers should check with boiler manufacturers to ensure that alterations will not adversely alter the performance, void the warranty, or create a hazardous situation.



Source: HydroTherm

The Multi-Pulse boiler from Hydrotherm offers an annual fuel utilization efficiency (AFUE) of over 90%. Multiple units can be ganged for higher output requirements.

Install automatic flue dampers to reduce the amount of boiler heat that is stripped away by natural convection in the flue after the boiler cycles off.

Retrofit gas pilots with electronic ignition systems, which are readily available.

Add automatic blowdown controls. Uncontrolled, continuous blowdown is very wasteful. A 10% blowdown on a 200 psia steam system results in a 3% efficiency loss. Add automatic blowdown controls that sense and respond to boiler water conductivity and pH.

Add a waste heat recovery system to blowdowns. Capturing blowdown in recovery tanks and using heat exchangers to preheat boiler feedwater can improve system efficiency by about 1%.

Consider retrofitting boiler fire tubes with turbulators for greater heat exchange, after checking with your boiler manufacturer. Turbulators are baffles placed in boiler tubes to increase turbulence, thereby extracting more heat from flue gases.

Insulate boiler and boiler piping. Reduce heat loss through boiler walls and piping by repairing or adding insulation. The addition of 1 inch (2.5 cm) of insulation can reduce heat loss by 80–90%.

OPERATION AND MAINTENANCE

Proper operation and maintenance is the key to efficient boiler operation. Any large boiler plant should maintain logs on boiler conditions as a diagnostic tool. When performance declines, corrective action should be taken.

Reduce soot and scale. Deposits act as insulation on heat exchangers and allow heat to escape up the flue. If the stack temperature rises over time under the same load and fuel/air mixture, and deposits are discovered, adjust and improve water chemistry and fuel/air mixture accordingly. Periodically running the system lean can remove soot.

Detect and repair steam leaks. Though they are not directly boiler-related, leaks in underground distribution pipes can go undetected for years. Monitor blowdown and feedwater to help detect these leaks. Repair them promptly.



On systems operating with negative pressure, air may enter the system after combustion and give false indications of excess air measured with flue-gas oxygen.

References

Brecher, Mark L., “Low-Pressure System Gets High Marks from College,” *Heating/Piping/Air Conditioning*, September 1994.

Payne, William, *Efficient Boiler Operations Sourcebook, 3rd Edition*, Fairmont Press, Lilburn, GA, 1991.

Washington State Energy Office, *Boiler Efficiency Operations* (WAOENG-89-24), Olympia, WA, 1989.

5.2.2

Air Distribution Systems

On an annual basis, continuously operating air distribution fans can consume more electricity than chillers or boilers, which run only intermittently. High-efficiency air distribution systems can substantially reduce fan power required by an HVAC system, resulting in dramatic energy savings. Because fan power increases at the square of air speed, delivering a large mass of air at low velocity is a far more efficient design strategy than pushing air through small ducts at high velocity. Supplying only as much air as is needed to condition or ventilate a space through the use of variable-air-volume systems is more efficient than supplying a constant volume of air at all times.

Opportunities

The largest gains in efficiency for air distribution systems are realized in the system design phase during new construction or major retrofits. Modifications to air distribution systems are difficult to make in existing buildings, except during a major renovation.

Technical Information

Design options for improving air distribution efficiency include (1) variable-air-volume (VAV) systems, (2) VAV diffusers, (3) low-pressure-drop ducting design, (4) low-face-velocity air handlers, (5) fan sizing and variable-frequency-drive (VFD) motors, and (6) displacement-ventilation systems. These are described below.

Deliver only the volume of air needed for conditioning the actual load. Variable-air-volume systems offer superior energy performance compared with constant-volume systems with dual ducts or terminal reheat that use backward-inclined or airfoil fans. VAV systems are becoming an increasingly standard design practice, yet even greater efficiency gains can be made through careful selection of equipment and system design.

Use local VAV diffusers for individual temperature control. Temperatures across a multiroom zone in a VAV system can vary widely, causing individuals



Facility managers can evaluate the benefits of reducing the size of fan systems in facilities by running EPA's QuikFan software. The software is available to Green Lights and ENERGY STAR® Building Partners.

further from the thermostat and VAV box location to be uncomfortable. Local ceiling diffusers ducted from the VAV box to individual rooms can modulate the amount of conditioned air delivered to a space, eliminating the inefficient practice of overheating or overcooling spaces to ensure the comfort of all occupants. VAV diffusers require low duct static pressures—0.25 inches of water column (62 Pa) or less—and thus save on fan energy.

Increase duct size to reduce duct pressure drop and fan speed. Eliminate resistance in the duct system by improving the aerodynamics of the flow paths and avoiding sharp turns in duct routing. Increasing the size of ducting where possible allows reductions in air velocity, which in turn permit reductions in fan speed and yield substantial energy savings. Small increases in duct diameter can yield large pressure drop and fan energy savings, because the pressure drop in ducts is proportional to the inverse of duct diameter to the fifth power.

Specify low-face-velocity air handlers—to reduce air velocity across coils. Oversizing the air handler increases the cross-sectional area of the airflow, allowing the delivery of the same required airflow at a slower air speed for only a relatively small loss of floor space. The pressure drop across the coils decreases with the square of the air speed, allowing the use of a smaller fan and smaller VFD, thus reducing the first-costs of those components. Air traveling at a lower velocity remains in contact with cooling coils longer, allowing warmer



Source: Krantz

Designed for use with access flooring systems, these passive air diffusers from Krantz swirl air, causing it to mix very quickly with surrounding air.



Half-round textile ducts in the Carlsson company's dining room (in Sweden) retain their shape even when not inflated with supply air.

Source: KE Fibertec North America

chilled water temperatures. This can yield substantial compounded savings through downsizing of the chilled water plant (as long as all air-handling units in a facility are sized with these design strategies in mind).

Size fans correctly and install VFDs on fan motors. Replace oversized fans with units that match the load. Electronically control the fan motor's speed and torque to continually match fan speed with changing building-load conditions. Electronic control of the fan speed and airflow can replace inefficient mechanical controls, such as inlet vanes or outlet dampers. (See Section 5.7.2 – Variable-Frequency Drives.)

Use the displacement method for special facility types. Displacement ventilation systems can largely eliminate the need for ducting by supplying air through a floor plenum and using a ceiling plenum or ceiling ducts as the return. Raised (access) floors providing



Be certain that proper ventilation and humidity control is provided by the air distribution system even when heating and cooling loads are low. If fans are set up to respond only to space temperature requirements, space ventilation can fall below acceptable limits during mild weather. This is a very important air quality issue.



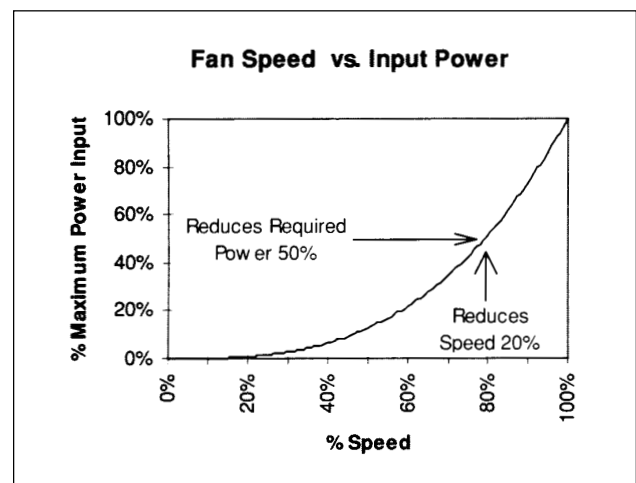
Using fabric ducting for exposed applications can help avoid duct cleaning difficulties. Conditioned supply air inflates the ducts and diffuses through the fabric into the occupied space, providing final filtration of the supply air in the process. Textile ducting can be removed and washed in conventional clothes washers at low labor costs, an important savings opportunity for sensitive areas that require frequent cleaning, such as food processing facilities.

air delivery are commonly used in Europe and rapidly gaining popularity in the United States. This design strategy is best used in (1) facilities that already include, or can accommodate, low-wall duct mounts or a floor plenum; (2) spaces with high ceilings, in which only a small band of air at the floor level needs to be conditioned for occupant comfort; (3) clean-room or laboratory spaces that require high-volume ventilation or laminar airflow; or (4) facilities in which other benefits of access floors, such as telecommunications wiring needs and high churn rate, are important. Because of the air delivery characteristics, the conditioned supply air does not have to be chilled as much, resulting in additional energy savings.

References

Variable Air Volume Systems: Maximum Energy Efficiency and Profits (430-R-95-002), U.S. Environmental Protection Agency, 1995; www.epa.gov.

Cler, Gerald, et al., *Commercial Space Cooling and Air Handling Technology Atlas*, E Source, Inc., Boulder, CO, 1997; (303) 440-8500; www.esource.com.



5.2.3 Chillers

In large Federal facilities, the equipment used to produce chilled water for HVAC systems can account for up to 35% of a facility's electrical energy use. If replacement is determined to be the most cost-effective option, there are some excellent new chillers on the market. The most efficient chillers currently available operate at efficiencies of 0.50 kilowatts per ton (kW/ton), a savings of 0.15 to 0.30 kW/ton over most existing equipment. When considering chiller types and specific products, part-load efficiencies must also be compared. If existing chiller equipment is to be kept, there are a number of measures that can be carried out to improve performance.

Opportunities

Consider chiller replacement when existing equipment is more than ten years old and the life-cycle cost analysis confirms that replacement is worthwhile. New chillers can be 30–40% more efficient than existing equipment. First-cost and energy performance are the major components of life-cycle costing, but refrigerant fluids may also be a factor. Older chillers using CFCs may be very expensive to recharge if a refrigerant leak occurs (and loss of refrigerant is environmentally damaging).

An excellent time to consider chiller replacement is when lighting retrofits, glazing replacement, or other modifications are being done to the building that will reduce cooling loads. Conversely, when a chiller is being replaced, consider whether such energy improvements should be carried out—in some situations those energy improvements can be essentially done for free because they will be paid for from savings achieved in downsizing the chiller (see *Section 4.1 – Integrated Building Design*). Be aware that there can be lead times of six months or more for delivery of new chillers.

Technical Information

Electric chillers use a vapor compression refrigerant cycle to transfer heat. The basic components of an electric chiller include an electric motor, refrigerant compressor, condenser, evaporator, expansion device, and

controls. Electric chiller classification is based on the type of compressor used—common types include centrifugal, screw, and reciprocating. The scroll compressor is another type frequently used for smaller applications of 20 to 60 tons. Hydraulic compressors are a fifth type (still under development).

Both the heat rejection system and building distribution loop can use water or air as the working fluid. Wet condensers usually incorporate one or several cooling towers. Evaporative condensers can be used in certain (generally dry) climates. Air-cooled condensers incorporate one or more fans to cool refrigerant coils and are common on smaller, packaged rooftop units. Air-cooled condensers may also be located remotely from the chillers.

REFRIGERANT ISSUES

The refrigerant issues currently facing facility managers arise from concerns about protection of the ozone layer and the buildup of greenhouse gases in the atmosphere. The CFC refrigerants traditionally used in most large chillers were phased out of production on January 1, 1996, to protect the ozone layer. CFC chillers still in service must be (1) serviced with stockpiled refrigerants or refrigerants recovered from retired equipment; or (2) converted to HCFC-123 (for the CFC-11 chillers) or HFC-134a (for the CFC-12 chillers); or (3) replaced with new chillers using EPA-approved refrigerants.

All refrigerants listed for chillers by the EPA Strategic New Alternatives Program (SNAP) are acceptable. These include HCFC-22, HCFC-123, HFC-134a, and ammonia for vapor-compression chillers (see table on page 63). Under current regulations, HCFC-22 will be phased out in the year 2020. HCFC-123 will be phased out in the year 2030. Chlorine-free refrigerants, such as HFC-134a and water/lithium bromide mixtures, are not currently listed for phase-out.

A chiller operating with a CFC refrigerant is not directly damaging to the ozone, provided that the refrigerant is totally contained during the chiller's operational life and that the refrigerant is recovered upon retirement. If a maintenance accident or leak results in venting of the CFC refrigerant into the atmosphere, however, damage to the Earth's ozone layer occurs. This risk should be avoided whenever possible.

Proper refrigerant handling is a requirement for any of the options relating to chillers operating with CFC refrigerants. The three options are containment, conversion, or replacement:

- **Containing refrigerant** in existing chillers is possible with retrofit devices that ensure that refrigerant leakage is eliminated. Containment assumes that phased-out refrigerants will continue to be available by recovering refrigerants from retired systems.
- **Converting chillers** to use alternative refrigerants will lower their performance and capacity. The capacity loss may not be a problem with converted units since existing units may have been oversized when originally installed and loads may have been reduced through energy conservation activities.
- **Replacing older chillers** that contain refrigerants no longer produced is usually the best option for complying with refrigerant phaseout requirements, especially if load reductions are implemented at the same time, permitting chiller downsizing.

SPECIFYING NEW CHILLERS

Chillers have been significantly reengineered in recent years to use new HCFC and HFC refrigerants. New machines have full-load efficiencies down to 0.50 kW/ton in the 170- to 2,300-ton range. Some have built-in refrigerant containment, are designed to leak no more than 0.1% refrigerant per year, and do not require purging.

Other important energy efficiency improvements in new chillers include larger heat transfer surfaces, microprocessor controls for chiller optimization, high-efficiency motors, variable-frequency drives, and optional automatic tube-cleaning systems. To facilitate replacement, new equipment is available from all manufacturers that can be unbolted for passage through conventional doors into equipment rooms. Many positive-pressure chillers are approximately one-third smaller than negative-pressure chillers of similar capacity.

Thermal energy storage may be added when replacing chillers and may enable the use of smaller chillers. Although this strategy does not save energy per se, operating costs may be reduced by lowering electrical demand charges and by using cheaper, off-peak electricity. Thermal storage systems commonly use one of three thermal storage media: water, eutectic salts, or ice. Volumes of these materials required for storage of 1 ton-hour of cooling are approximately 11.4, 2.5, and 1.5 ft³ (0.33, 0.07, and 0.04 m³), respectively.

Multiple chiller operations may be made more efficient by using *unequally sized* units. With this configuration, the smallest chiller can efficiently meet light loads. The other chillers are staged to meet higher loads after the lead chiller is operating close to full capacity. If an existing chiller operates frequently at part-load conditions, it may be cost-effective to replace it with multiple chillers staged to meet varying loads.

Double-bundle chillers have two possible pathways for rejecting condenser heat. One pathway is a conventional cooling tower. The other pathway is heat

(continued on next page)

COMPARISON OF REFRIGERANT ALTERNATIVES

Criteria	HCFC-123	HCFC-22	HFC-134a	Ammonia
Ozone-depletion potential	0.016	0.05	0	0
Global warming potential (relative to CO ₂)	85	1,500	1,200	0
Ideal kW/ton	0.46	0.50	0.52	0.48
Occupational risk	Low	Low	Low	Low
Flammable	No	No	No	Yes

Source: U.S. Environmental Protection Agency

5.2.3 Chillers (continued)

recovery for space heating or service-water heating. Candidates for these chillers are facilities in cold climates with substantial hours of simultaneous cooling and heating demands. Retrofitting existing water heating may be difficult, because of the low temperature rise available from the heat-recovery loop.

Steam or hot water absorption chillers use mixtures of water/lithium-bromide or ammonia/water that are heated with steam or hot water to provide the driving force for cooling. This eliminates global environmental concerns about refrigerants used in vapor-compression chillers. Double-effect absorption chillers are significantly more efficient than single-effect machines. (See *Section 5.2.4 – Absorption Cooling*.)

Specifying and procuring chillers should include load-reduction efforts, careful equipment sizing, and good engineering. Proper sizing is important in order to save on both initial costs and operating costs. Building loads often decrease over time as a result of conservation measures, so replacing a chiller should be accomplished only after recalculating building loads. Published standards such as ASHRAE 90.1 and DOE standards provide guidance for specifying equipment. Procuring energy-efficient, water-cooled electric chillers has been made considerably easier for facility managers through the BOA developed by DOE and GSA that specifies desired equipment parameters.

UPGRADING EXISTING CHILLERS

A number of alterations may be considered to make existing chiller systems more energy efficient. Careful engineering is required before implementing any of these opportunities to determine the practicality and economic feasibility.

Variable-frequency drives provide an efficient method of reducing the capacity of centrifugal chillers and thus saving energy. Note that VFDs are typically installed at the factory. Savings can be significant, provided that (1) loads are light for many hours per year, (2) the climate does not have a constant high wet-bulb temperature, and (3) the condenser water temperature can be reset higher under low part-load conditions. (See *Section 5.7.2 – Variable-Frequency Drives*.)

Chiller bypass systems can be retrofitted into central plants, enabling waterside economizers to cool spaces with chillers off-line. In these systems, the cooling tower provides chilled water either directly with filtering or indirectly with a heat exchanger. These systems are applicable when (1) chilled water is required many hours per year, (2) outdoor temperatures are below 55°F (13°C), (3) air economizer cycles cannot be used, and (4) cooling loads below 55°F (13°C) do not exceed 35–50% of full design loads.

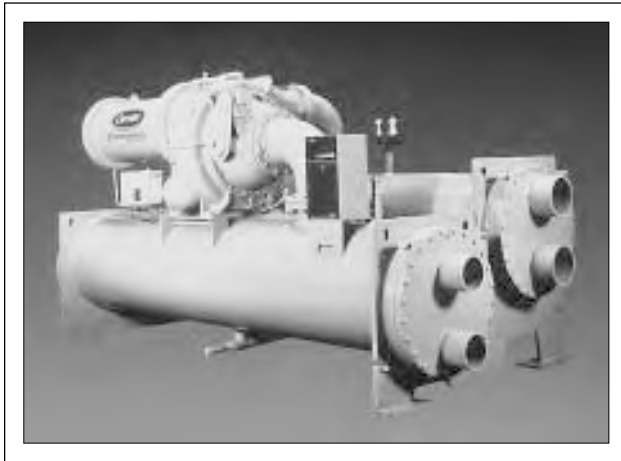
Other conservation measures to consider when looking at the chiller system upgrades include:

- Higher-efficiency pumps and motors;
- Operation with low condenser water temperatures;
- Low-pressure-drop evaporators and condensers (oversized chiller “barrels”);
- Interconnecting multiple chillers into a single system;
- Upgrading cooling towers; and
- Upgrading control systems (e.g., temperature reset).



Overall HVAC system efficiency should be considered when altering chiller settings.

The complex interrelationships of chiller system components can make it difficult for operators to understand the effects of their actions on all components of the systems. For example, one way to improve chiller efficiency is to decrease the condensing water temperature. However, this requires additional cooling tower operation that may actually increase total operating costs if taken to an extreme. In humid climates, increasing the chilled water temperature to save energy may unacceptably reduce the effective removal of humidity if the coil size is not also adjusted.



Carrier Corporation's Evergreen line of chillers was the first one specifically designed to accommodate non-ozone-depleting HFC-134a refrigerant. Source: Carrier Corporation

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Fryer, Lynn, *Electric Chiller Buyer's Guide: Water-Cooled Centrifugal and Screw Chillers*, Technical Manual, E Source, Inc., Boulder, CO, 1995; (303) 440-8500; www.esource.com.

Cler, Gerald, et al., *Commercial Space Cooling and Air Handling Technology Atlas*, E Source, Inc., Boulder, CO, 1997 (see contact information above).

Contacts

For more information about the Basic Ordering Agreement (BOA) for energy-efficient water-cooled chillers, contact the General Services Administration at (817) 978-2929.



ROOFTOP RETROFITS

Many Federal buildings are cooled via roof-mounted direct-expansion (DX) air conditioners. If the individual rooftop DX units are old and inefficient, it may be possible to retrofit them to use a single high-efficiency chiller (18 or higher energy-efficiency rating [EER]). In the retrofit process, the existing evaporator coils are adapted to use glycol that is cooled by the chiller. Ice storage may be incorporated as part of the rooftop retrofit. The chiller can be operated at night to make ice, which would provide or supplement cooling during the day. This retrofit system provides an efficient means of reducing on-peak electric demand, as discussed in this section under *Thermal Storage*. FEMP estimates a very high savings potential from this system. If all rooftop DX systems used in Federal buildings were replaced by chillers, more than 50% of the electricity used by rooftop units could be saved. Available space for the chiller and, if included, ice storage, is a consideration with this type of retrofit.

On the surface, the idea of using an open flame or steam to generate cooling might appear contradictory, but the idea is actually very elegant. And it has been around for quite a while—the first patent for absorption cooling was issued in 1859 and the first system built in 1860. Absorption cooling is more common today than most people realize. Large, high-efficiency, double-effect absorption chillers using water as the refrigerant dominate the Japanese commercial air-conditioning market. While less common in the U.S., interest in absorption cooling is growing, largely as a result of deregulation in the electric power industry. The technology is even finding widespread use in hotels that use small built-in absorption refrigerators (because of their virtually silent operation) and for refrigerators in recreational vehicles (because they do not require electricity).

Opportunities

Absorption cooling is most frequently used to air-condition large commercial buildings. Because there are no simplifying rules of thumb to help determine when absorption chillers should be used, a life-cycle cost analysis should be performed on a case-by-case basis to determine whether this is an appropriate technology. Absorption chillers may make sense in the following situations: where there are high electric demand charges, where electricity use rates are high, where summertime natural gas prices are favorable, or where utility and manufacturer rebates exist. Absorption chillers can be teamed with electric chillers in “hybrid” central plants to provide cooling at the lowest energy costs—in this case, the absorption chillers are used during the summer to avoid high electric demand charges, and the electric chillers are used during the winter when they are more economical. Because absorption chillers can make use of waste heat, they can essentially provide free cooling in certain facilities.

Absorption cooling systems can most easily be incorporated into new construction, though they can also be used as replacements for conventional electric chillers. A good time to consider absorption cooling is when an old electric chiller is due for replacement.

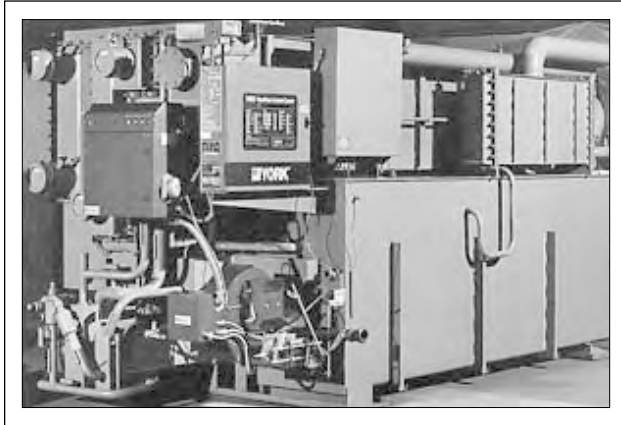
Technical Information

An absorption cooling cycle is similar to a vapor-compression cycle in that it relies on the same three basic principles (1) when a liquid is heated it boils (vaporizes), and when a gas is cooled it condenses; (2) lowering the pressure above a liquid reduces its boiling point; and (3) heat flows from warmer to cooler surfaces. Instead of mechanically compressing a gas (as occurs with a vapor-compression refrigeration cycle), absorption cooling relies on a thermochemical “compressor.” Two different fluids are used, a refrigerant and an absorbent, that have high “affinity” for each other (one dissolves easily in the other). The refrigerant (usually water) can change phase easily between liquid and vapor and circulates through the system. Heat from natural gas combustion or a waste-heat source drives the process. The high affinity of the refrigerant for the absorbent (usually lithium bromide or ammonia) causes the refrigerant to boil at a lower temperature and pressure than it normally would and transfers heat from one place to another.

Absorption chillers can be direct-fired or indirect-fired, and they can be single-effect or double-effect (explanation of these differences is beyond the scope of this discussion). Double-effect absorption cycles capture some internal heat to provide part of the energy required in the generator or “desorber” to create the high-pressure refrigerant vapor. Using the heat of absorption reduces the steam or natural gas requirements and boosts system efficiency.

Absorption cooling equipment on the market ranges in capacity from less than 10 tons to over 1,500 tons (35 to 5,300 kW). Coefficients of performance (COPs) range from about 0.7 to 1.2, and electricity use ranges from 0.004 to 0.04 kW/ton of cooling. Though an electric pump is usually used (the principal exceptions being the small hotel and recreational vehicle [RV] refrigerators), pump energy requirements are relatively small because pumping a liquid to the high-side pressure requires much less electricity than does compressing a gas to the same pressure.

High-efficiency, double-effect absorption chillers are more expensive than electric-driven chillers. They require larger heat exchangers because of higher heat-rejection loads; this translates directly into higher



Source: American Gas Cooling Center

This York® Millennium™ Direct-Fired Double-Effect Absorption Chiller/Heater replaces an electric chiller and boiler, reducing the floor-space requirement by up to 40%.

costs. Non-energy operating and maintenance costs for electric and absorption chillers are comparable. Significant developments in controls and operating practice have led the current generation of double-effect absorption chillers to be praised by end-users for their low maintenance requirements.

The potential of absorption cooling systems to use waste heat can greatly improve their economics. Indirect-fired chillers use steam or hot water as their primary energy source, and they lend themselves to integration with on-site power generation or heat recovery from incinerators, industrial furnaces, or manufacturing equipment. Indirect-fired, double-effect absorption

chillers require steam at around 370°F and 115 psig (190°C and 900 kPa), while the less efficient (but also less expensive) single-effect chillers require hot water or steam at only 167–270°F (75–132°C). Triple-effect chillers are also available.

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ASHRAE Handbook: 1997 Fundamentals, pp. 1-20, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Atlanta, GA; www.ashrae.org.

Wood, Bernard D., *Application of Thermodynamics*, Addison-Wesley Publishing Company, Reading, MA, 1982, pp. 238-257.

Contacts

Distributed Energy Resources Program, Office of Power Technologies, EERE, U.S. Department of Energy, 1000 Independence Avenue, SW, Washington, DC 20585.

Building Equipment Research Program, Energy Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831; (865) 574-2694.

American Gas Cooling Center, 400 N. Capitol Street, NW, Washington, DC 20001; (202) 824-7141, www.agcc.org.

TYPICAL INSTALLED COSTS OF VARIOUS TYPES OF CHILLERS (\$/TON)

CHILLER TYPE	SMALL (<500 tons)	MEDIUM (500–1,000 tons)	LARGE (1,000–1,500 tons)
Electrically Driven	\$300	\$280	<\$280
Single-Effect Absorption	\$285	\$210	\$195
Double-Effect Absorption	\$600	\$525–\$550	\$460

Source: Supersymmetry USA

5.2.5

Desiccant Dehumidification

Desiccants are materials that attract and hold moisture, and desiccant air-conditioning systems provide a method of drying air before it enters a conditioned space. With the high levels of fresh air now required for building ventilation, removing moisture has become increasingly important. Desiccant dehumidification systems are growing in popularity because of their ability to remove moisture from outdoor ventilation air while allowing conventional air-conditioning systems to deal primarily with control temperature (sensible cooling loads).

Opportunities

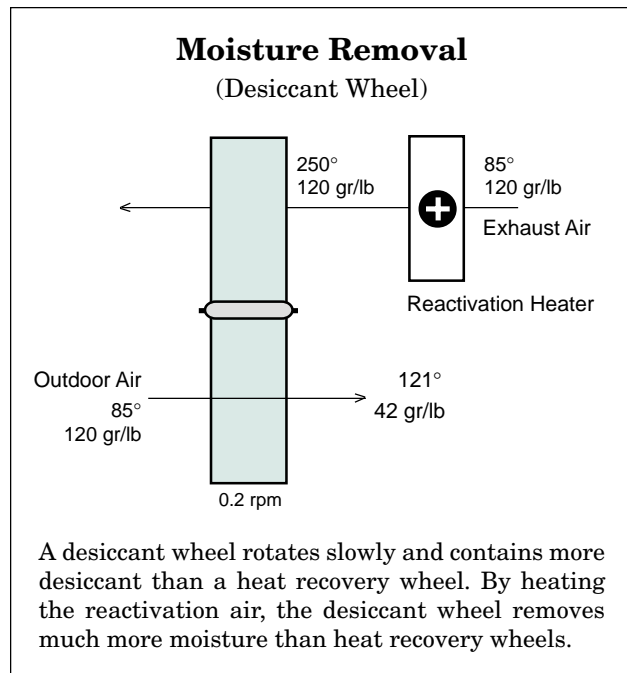
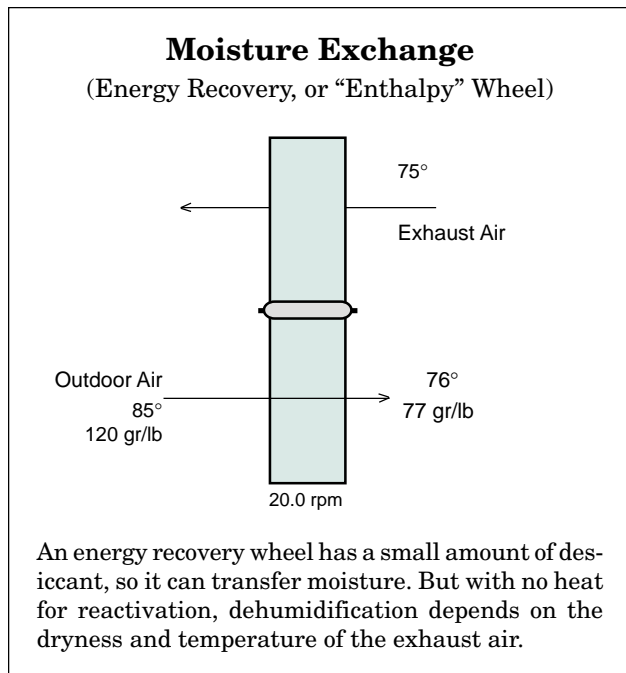
Desiccant dehumidification is a new approach to space-conditioning that offers solutions for many of the current economic, environmental, and regulatory issues being faced by facility managers. Indoor air quality is improved through higher ventilation rates, and achieving those fresh air make-up rates becomes more feasible with desiccant systems. At “low load conditions” outdoor air used for ventilation and recirculated air from the building have to be dehumidified more than they have to be cooled.

Properly integrated desiccant dehumidification systems have become cost-effective additions to many building HVAC systems because of:

- Their ability to recover energy from conditioned air that is normally exhausted from buildings.
- The lower cost of dehumidification when low-sensible load, high-latent load conditions are met.
- The greater comfort achieved with dehumidified air.
- The promotion of gas cooling for summer air-conditioning by utilities in the form of preferential gas cooling rates.
- High electric utility demand charges, which encourage a shift away from conventional, electrically driven air-conditioning (which requires a heavy daytime loading).

Desiccant systems offer significant potential for energy savings (0.1 to 0.4 quads nationwide). They also inhibit microbiological growth by maintaining lower humidity levels. Better control of humidity prevents moisture, mildew, and rot damage to building materials.

Desiccant dehumidification is particularly attractive in applications where building exhaust air is readily available for an energy-recovery ventilator (ERV, or “passive” desiccant system) or where a source of waste heat from other building operations is available to regenerate an “active” desiccant system.



“Passive” versus “active” desiccant wheels

Adapted from American Gas Cooling Center materials



Source: American Gas Cooling Center

The DRYOMATIC Dehumidification System from the Air-flow Company may be installed indoors or outdoors.

Technical Information

To dehumidify air streams, desiccant materials are impregnated into a lightweight honeycomb or corrugated matrix that is formed into a wheel. This wheel is rotated through a supply or process air stream on one side that is dried by the desiccant before being routed into the building. The wheel continues to rotate through a reactivation or regeneration air stream on the other side that dries out the desiccant and carries the moisture out of the building. The desiccant can be reactivated with air that is either hotter or drier than the process air.

“Passive” desiccant wheels, which are used in total ERVs and enthalpy exchangers, use dry air that is usually building exhaust air for regeneration. Passive desiccant wheels require additional fan power only to move the air and the energy contained in the exhaust air stream. However, passive desiccants cannot remove as much moisture from incoming ventilation air as active desiccant systems and are ultimately limited in *sensible* and *latent* capacity by the temperature and dryness of exhaust air leaving the building.

“Active” desiccant wheels use heated air and require a thermal energy source for regeneration. The illustration above shows the operational characteristics of active and passive desiccant wheels. The advantage of active desiccant wheels is that they dry the supply air continuously—to any desired humidity level—in all weather, regardless of the moisture content of the building’s exhaust air. They can be regenerated with



Because the sizing of desiccant systems is based on the airflow rate (cfm), costs are typically given in terms of \$/cfm. Passive desiccant system costs have been estimated by one HVAC manufacturer at \$3 to \$4/cfm. For large, active desiccant systems, the cost is usually about \$6/cfm, while smaller units (less than 5,000 cfm) may cost up to \$8/cfm. Installation costs vary according to specific site requirements.

natural gas combustion or another heat source, independent of—or in combination with—building exhaust air, which allows more installation flexibility. The regeneration process, however, requires heat input to dry the desiccant; this usually increases the operating cost of the system. Active desiccant wheels can remove much more moisture than passive systems and thus are the only desiccant approach that allows truly *independent* humidity control to any desired level.

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“Applications Engineering Manual for Desiccant Systems,” American Gas Cooling Center, Washington, DC, 1996.

Contacts

Distributed Energy Resources Program, Office of Power Technologies, EERE, U.S. Department of Energy, 1000 Independence Avenue, SW, Washington, DC 20585-0121.

Building Equipment Research Program, Energy Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831-6070; (865) 574-2694.

American Gas Cooling Center, Inc., 400 N. Capitol Street, NW, Washington, DC 20001; (202) 824-7141; www.agcc.org.

Advanced Desiccant Cooling & Dehumidification Program, National Renewable Energy Laboratory, 1617 Cole Boulevard, Golden, CO 80401; (303) 384-7527; www.nrel.gov/desiccantcool.

5.2.6

Ground-Source Heat Pumps

Heat pumps function by moving (or pumping) heat from one place to another. Like a standard air-conditioner, a heat pump takes heat from inside a building and dumps it outside. The difference is that a heat pump can be reversed to take heat from a heat source outside and pump it inside. Heat pumps use electricity to operate pumps that alternately evaporate and condense a refrigerant fluid to move that heat. In the heating mode, heat pumps are far more “efficient” at converting electricity into usable heat because the electricity is used to *move* heat, not to generate it.

The most common type of heat pump—an air-source heat pump—uses outside air as the *heat source* during the heating season and the *heat sink* during the air-conditioning season. *Ground-source* and *water-source* heat pumps work the same way, except that the heat source/sink is the ground, groundwater, or a body of surface water, such as a lake. (For simplicity, water-source heat pumps are often lumped with ground-source heat pumps, as is the case here.) The efficiency or *coefficient of performance* of ground-source heat pumps is significantly higher than that

of air-source heat pumps because the heat source is warmer during the heating season and the heat sink is cooler during the cooling season. Ground-source heat pumps are also known as *geothermal* heat pumps, though this is a bit of a misnomer since the ultimate heat source with most ground-source heat pumps is really solar energy—which maintains the long-term earth temperatures within the top few meters of the ground surface. Only deep-well ground-source heat pumps that benefit from much deeper earth temperatures may be actually utilizing geothermal energy.

Ground-source heat pumps are environmentally attractive because they deliver so much heat or cooling energy per unit of electricity consumed. The COP is usually 3 or higher. The best ground-source heat pumps are more efficient than high-efficiency gas combustion, even when the *source efficiency* of the electricity is taken into account.

Opportunities

Ground-source heat pumps are generally most appropriate for residential and small commercial buildings,

such as small-town post offices. In residential and small (skin-dominated) commercial buildings, ground-source heat pumps make the most sense in mixed climates with significant heating and cooling loads because the high-cost heat pump replaces both the heating and air-conditioning system. In larger buildings (with significant internal loads), the investment in a ground-source heat pump can be justified further north because air-

conditioning loads increase with building size. *Packaged terminal heat pumps*, used in hotels and large apartment buildings, are similar except that the heat source is a continuously circulating source of chilled water—the individual water-source heat pumps provide a fully controllable source of heat or air-conditioning for individual rooms.

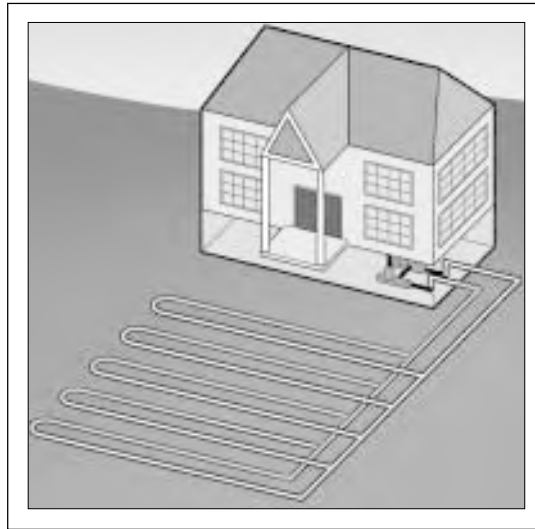
Because ground-source heat pumps are expensive to install in residential and small commercial buildings, it sometimes makes better economic sense to invest in energy efficiency measures that significantly reduce heating and cooling loads, then install less expensive heating and cooling equipment—the savings in equipment may be able to pay

for most of the envelope improvements (see *Section 4.1 – Integrated Building Design*). If a ground-source heat pump is to be used, plan the site work and project scheduling carefully so that the ground loop can be installed with minimum site disturbance or in an area that will be covered by a parking lot or driveway.

Technical Information

Ground-source heat pumps are generally classified according to the type of loop used to exchange heat with the heat source/sink. Most common are closed-loop horizontal (see the illustration above) and closed-loop vertical systems. Using a body of water as the heat source/sink is very effective, but seldom available as an option. Open-loop systems are less common than closed-loop systems due to performance problems (if detritus gets into the heat pump) and risk of contaminating the water source or—in the case of well water—inadequately recharging the aquifer.

Ground-source heat pumps are complex. Basically, water or a nontoxic antifreeze-water mix is circulated through buried polyethylene or polybutylene piping.





Horizontal-loop ground-source heat pumps typically have tubing buried within the top 10 feet (3 m) of ground.


Source: Al Paul Lefton Company

This water is then pumped through one of two heat exchangers in the heat pump. When used in the heating mode, this circulating water is pumped through the cold heat exchanger, where its heat is absorbed by evaporation of the refrigerant. The refrigerant is then pumped to the warm heat exchanger, where the refrigerant is condensed, releasing heat in the process. This sequence is reversed for operation in the cooling mode.

Direct-exchange ground-source heat pumps use copper ground-loop coils that are charged with refrigerant. This ground loop thus serves as one of the two heat exchangers in the heat pump. The overall efficiency is higher because one of the two separate heat exchangers is eliminated, but the risk of releasing the ozone-depleting refrigerant into the environment is greater. DX systems have a small market share.

 **Free Hot Water:** When used in the cooling mode, a ground-source heat pump with a *desuperheater* will provide free hot water. Buildings in more southern climates that use a ground-source heat pump primarily for cooling can obtain a high percentage of hot water demand in this manner. Look for a ground-source heat pump that includes a *desuperheater* module.

 Typical system efficiencies and costs of a number of heating, cooling, and water-heating systems for residential and light commercial buildings are shown in the table below (from EPA, 1993). Of all the systems listed, ground-source heat pumps are the most expensive to install but the least expensive to operate.

 **Improving Performance:** There are a number of ways to improve ground-source heat pump performance. Cooling-tower-supplemented systems can reduce the total size of the ground loop required to meet cooling demand. A cooling tower is added to the ground-coupled loop by means of a heat exchanger. Solar-assisted systems use solar energy to supplement heating in northern climates. Solar panels boost the temperature of the ground loop.

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Contacts

Geothermal Heat Pump Consortium, 701 Pennsylvania Avenue, NW, Washington, DC 20004; (888) 255-4436, (202) 508-5500, (202) 508-5222 (fax); www.geoexchange.org.

U.S. Department of Energy; www.eren.doe.gov/ or www.energy.gov.

SEASONAL PERFORMANCE FACTORS⁽¹⁾

Space-Conditioning System	Heating	Cooling	Hot Water	Installed Cost	Ann. Op. Cost
Electric resistance with elec. A/C	1.00	2.3–2.6	0.90	\$5,415–5,615	\$871–2,945
Gas furnace with elec. A/C	0.64–0.87	2.3–3.2	0.56–0.60	\$5,775–7,200	\$461–1,377
Adv. oil furnace with elec. A/C	0.73	3.1–3.2	0.90	\$6,515	\$1,162–1,370
Air-source heat pump	1.6–2.9	2.3–4.3	0.90–3.1	\$5,315–10,295	\$353–2,059
Ground-source heat pump	2.7–5.4	2.8–6.0	1.2–3.0	\$7,520–10,730	\$274–1,179

1. Seasonal performance factors represent seasonal efficiencies for conventional heating and cooling systems and seasonal COPs for heat pumps. Ranges show modeled performance by EPA in different climates.

Source: U.S. Environmental Protection Agency, *Space Conditioning: The Next Frontier*, 1993

New (or generally unfamiliar) HVAC technologies can help facility managers lower energy costs, reduce environmental impacts, and enhance indoor environmental quality. Information is provided here on a number of these technologies. Some of the new technologies covered in this section of the first edition of *Greening Federal Facilities* (1997) are now in fairly widespread use and merit their own sections of the guide (ground-source heat pumps, absorption cooling, and desiccant dehumidification). Other technologies have been added to this section. Although new technologies may be available only from a single manufacturer, and although the energy performance data are sometimes limited, these systems are worth considering.

Opportunities

Not every Federal facility will be able to try out relatively new or unfamiliar technologies, but as these systems become better known and trusted, potential applications will grow. Ventilation-preheat solar collectors are demonstrated to be highly cost-effective in hundreds of cold-climate applications. A number of the technologies described here can help control indoor humidity. In arid climates, evaporative cooling and an innovative rooftop evaporative system can be effective. Where electrical power demand costs are high, natural-gas engine-driven cooling may be appropriate.

Technical Information

VENTILATION-PREHEAT SOLAR COLLECTORS (TRANSPIRED AIR COLLECTORS)

This very simple solar collector passively preheats ventilation make-up air via a large, unglazed solar collector. These collectors are most effective on south-facing building facades, though significant deviation off true south (plus-or-minus about 60°) results in only minor loss of performance. The Canadian company Conservall Engineering, Inc., has pioneered this system under the tradename Solarwall. The sheet-metal collector has perforations that allow air to pass through into corrugated air channels under the outer building skin. The ventilation system air intakes are configured so that make-up air is drawn through the collector before it enters the building.

In new construction, installation costs are typically in the range of \$6 to \$7 per square foot (\$65–\$75/m²), though if the sheet metal facade replaces a more expensive facing, such as brick, there may actually be a *net reduction in cost* for this ventilation preheat system. With retrofit applications, costs are usually somewhat higher than with new construction.



Fort Carson uses a ventilation-preheat solar collector wall to warm outside fresh air before it enters an aircraft hanger. Intake air is preheated by 30–50°F (17–28°C). Such systems can reduce annual heating cost by \$1–\$3 per square foot (\$11–\$32/m²) of collector wall, depending on fuel type, significantly reducing demand on boiler systems.

NATURAL GAS ENGINE-DRIVEN COOLING

An engine-driven cooling system is similar to a conventional electric cooling system, except that the compressor is driven by a natural gas engine rather than an electric motor. Configurations include chillers, packaged direct-expansion units, and heat pumps, usually in sizes from 200 tons to 4,000 tons. Engine-driven systems are variable-speed, have higher part-load efficiencies, generate high-temperature waste heat (that can be used), and can often reduce operating costs. Consider engine-driven natural gas cooling when electrical demand charges are high or natural gas is particularly inexpensive.

COOLING EQUIPMENT WITH ENHANCED DEHUMIDIFICATION

Reducing indoor humidity is a prime factor in discouraging microbiological growth in the indoor environment. *Section 5.2.5* addresses desiccant dehumidification. Heat pipes can also be used to efficiently remove moisture with direct-expansion or DX cooling. Heat pipes enable DX coils to remove more moisture by pre-cooling return air. Heat absorbed by the refrigerant in the heat pipe can then be returned to the overcooled, dehumidified air coming out of the DX coils. The system is passive, eliminating the expense of active re-heat systems. Somewhat more fan energy is required to maintain duct static pressure, as is the case when any new element is added to the ventilation system, but no additional pumps or compressors are required. Increased fan energy must be considered when calculating system energy savings. Energy savings up to 30% have been reported. At least one manufacturer builds a variable-dehumidification system for DX equipment that precools liquid refrigerant rather than the air stream.

EVAPORATIVE COOLING TECHNOLOGIES

Evaporative coolers (also known as swamp coolers) have been used for many years in hot, arid parts of the



Each innovative “air tree” above provides ventilation for six offices at the National Renewable Energy Laboratory’s (NREL’s) Solar Energy Research Facility in Golden, Colorado. Air is cooled and humidified by direct evaporation, or “swamp cooling.”

Photo: Warren Gretz

country. These systems are typically roof-mounted. Cooling is provided as hot, dry outside air is blown through an evaporative media that is kept moist. *Indirect* evaporative coolers can work in climates where moist air is not wanted in the building, though efficiency is lower.

On larger buildings in hot, dry climates, the benefits of evaporative cooling can be achieved through roof-spray technology. A modified spray-irrigation system can be used on the roof to drop daytime roof-surface temperatures from 135–160°F to 85–90°F (57–71°C to 29–32°C). With a typical (poorly insulated) roof system, this can reduce interior temperatures significantly.

A newer, more innovative use of evaporative cooling is *night-sky radiant cooling*. This approach works in climates with large diurnal temperature swings and generally clear nights (such as in the Southwest). Water is sprayed onto a low-slope roof surface at night, and the water is cooled through a combination of evaporation and radiation. This process typically cools the water to 5–10°F (2.7–5.5°C) below the night air temperature. The water drains to a tank in the basement or circulates through tubing embedded in a concrete floor slab. Daytime cooling is accomplished either by circulating cooled water from the tank or through passive means from the concrete slab. Developed by the Davis Energy Group and Integrated Comfort, Inc., this NightSky™ system was used at the U.S. Customs border patrol station in Nogales, Arizona, and monitored by Pacific Northwest National Laboratory (PNNL) in 1997. The average cooling efficiency was found to be nearly 15 times greater than that of conventional compressor-based air-conditioning systems.

REFRIGERANT SUBCOOLING

Refrigerant subcooling systems save energy in air conditioners, heat pumps, or reciprocating, screw and scroll chillers by altering the vapor-compression refrigerant cycle. Three types of refrigerant subcooling technologies are being manufactured, and each adds a heat exchanger on the liquid line after the condenser: (1) suction-line heat exchangers, which use the suction-line as a heat sink; (2) mechanical subcoolers that use a small, efficient, secondary vapor-compression system for subcooling; and (3) external heat-sink subcoolers that used a mini-cooling tower or ground-source water loop as a heat sink. Subcoolers increase energy efficiency, cooling capacity, and expansion valve performance (i.e., decrease flash gas).

Heat sink subcooling can be used (1) where units are being replaced; (2) where building expansion is planned; or (3) where current capacity is inadequate. The best applications are in climates that are hot year-round—1,200 or more base-65°F (18°C) cooling-degree days—and with DX systems. With external heat sink subcooling, condensing units and compressors should be downsized, making the technology more appropriate when existing equipment is being replaced, when construction or expansion is planned, or when current cooling capacity is inadequate. PNNL’s evaluation of subcooling in Federal facilities is contained in a *Federal Technology Alert* available from FEMP.

References

Space Conditioning: The Next Frontier, U.S. Environmental Protection Agency, Washington, DC, 1993.

Space Heating Technology Atlas (1996) and *Commercial Space Cooling and Air Handling Technology Atlas* (1997), E Source, Inc., Boulder, CO; (303) 440-8500; www.esource.com.

Natural Gas Cooling Equipment Guide, American Gas Cooling Center, Washington, DC, 1995.

Contacts

For information about all types of gas cooling equipment, contact the American Gas Cooling Center, 400 N. Capitol Street, NW, Washington, DC 20001; (202) 824-7141; www.agcc.org.

Federal Technology Alerts and other publications about new HVAC technologies are available from the FEMP Help Desk at (800) DOE-EREC (363-3732), or see the FEMP Web site at www.eren.doe.gov/femp.

Conserval Engineering, Inc., 200 Wildcat Road, Downsview, Ontario M3J 2N5, Canada; (416) 661-7057; www.solarwall.com.

Davis Energy Group, 123 C Street, Davis, CA 95616; (530) 757-4844; www.davisenergy.com.

Hot water is used in Federal facilities for handwashing, showering, janitorial cleaning, cooking, dishwashing, and laundering. Facilities often have significant needs for hot water in one or more locations and many smaller needs scattered throughout the facility. Methods for reducing water-heating energy use include maintaining equipment, implementing water conservation, reducing hot water temperatures, reducing heat losses from the system, utilizing waste heat sources, and replacing equipment with higher-efficiency or renewable-energy systems.

Opportunities

Reducing the demand for hot water should be the first priority, and it can be implemented at virtually any facility through efficiency measures and by matching the water temperatures to the task. Beyond that, consider upgrading to higher-efficiency water-heating equipment or shifting to other water-heating technologies whenever equipment is being replaced or major remodeling is planned. Rooftop solar water-heating equipment should be considered—especially at the time of reroofing. Heat-recovery water heating can be considered when modifying plumbing, HVAC, power-generation, or industrial-process systems that generate waste heat. Plan ahead and select a technology for use in the event that existing water-heating equipment fails; don't just replace-in-kind.

Technical Information

WATER HEATING TECHNOLOGIES

Solar water heating captures energy from the sun for heating water. These systems have improved significantly in recent years and make economic sense in many areas. See *Section 5.3.2 – Solar Water Heating*.

Standard electric water heaters both heat and store water in insulated storage tanks. Many older units have inadequate insulation and should be replaced or fitted with insulation jackets to improve performance.

Tankless or demand electric water heaters eliminate standby losses by heating water only as it is needed. They are usually located at the point of use and are convenient for remote areas having only occasional use; however, because of very high power consumption, they can increase electric demand charges.

Steam-fired water heaters utilize centrally produced steam for heating water. These units are popular in

commercial kitchens where steam is also used for cookers. Where boilers must be kept operating during summer months to supply small amounts of steam for kitchen purposes, changing to alternative water heating can be extremely cost-effective and possibly extend the life of the boiler.

Standard gas-fired water heaters use natural gas or propane burners located beneath storage tanks. Standby losses tend to be high because internal flues are uninsulated heat-exchange surfaces. Equipment should be direct-vented or sealed-combustion to minimize the risk of combustion gas spillage into the building.

Condensing gas water heaters have higher efficiency because the latent heat of vaporization is reclaimed from the combustion gases. Flue gases are cool enough to permit venting with special PVC pipe.

Tankless or demand gas water heaters are usually installed near the point of use. These are often good options for remote sites where there is adequate gas piping, pressure, and venting. Some recent developments—including higher-efficiency models with precise controllability and potential for ganging multiple units together for whole-building, staged use—are extending the practical applications for demand gas water heaters.

Direct-fire water heaters are gas-fired, demand water heaters for users of large quantities of potable water—up to several hundred gallons per minute. Using technology in existence since 1908, they mix the heat of combustion (not flame) directly with incoming water, achieving in excess of 98% efficiency while eliminating standby losses. Though expensive, these systems (produced by several manufacturers) can be very cost-effective for facilities using large quantities of hot water.

Air-source heat pump water heaters are specialized vapor-compression machines that transfer heat from the air into domestic water. Commercial kitchens and laundries are excellent opportunities because both indoor air temperatures and hot water needs are high. In the process of capturing heat, the air is both cooled and dehumidified, making space conditions more comfortable. Air-source heat pumps are recommended only if the air source is warmed by waste heat.

Ground-source and water-source heat pump water heaters are dedicated heat pumps that heat domestic water from energy captured from a water source. The heat source may be groundwater that is used for its stable year-round temperature, or a low-grade waste heat source. Ground-source heat pumps circulate the water through buried heat exchanger tubing.



Source: Direct Fire Technical, Inc.

Though requiring a high first-cost investment, a direct-fire water heater is so energy-efficient that its payback period can be short.

Desuperheaters are connected to air-conditioners, heat pumps, or refrigeration compressors. Hot refrigerant gas from the compressor is routed to the gas side of the unit's heat exchanger. Water is essentially heated for free whenever the air-conditioner, heat pump, or refrigerator compressor is operating. When a desuperheater is connected to a heat pump operating in *heating* mode, some of the heat pump's capacity is devoted to water heating.

Drainline heat exchangers are very simple, passive copper coils wrapped around wastewater drain lines. The cold-water line leading to the water heater passes through this coil, and water is preheated by hot water going down the drain. These low-cost systems are cost-effective in residential buildings (typically mounted to capture waste heat from showers). They can also work well in commercial buildings with significant hot water use.

IMPROVING WATER HEATER PERFORMANCE AND SAVING ENERGY

Insulate tanks and hot-water lines that are warm to the touch. Only recently have manufacturers installed adequate amounts of insulation on water heater tanks. Hot-water lines should be continuously insulated from the heater to the end use. Cold-water lines also should be insulated near the tank to minimize

convective losses (and everywhere if high humidity is likely to cause condensation).

Limit operating hours of circulating pumps. Large facilities often circulate domestic hot water to speed its delivery upon demand. By turning off those pumps when facilities are not being used (nights and weekends, for example), both the cost of operating the pump and heat losses through pipe walls will be reduced.

Install heat traps. Heat traps are plumbing fittings that block convective heat losses from water storage tanks.

Install water heaters near the points of most frequent use to minimize heat losses in hot water pipes. Note, this location will not necessarily be where the most hot water is used.

Eliminate leaks. Delays in repairing dripping faucets not only waste water and energy but often lead to more expensive repairs because of valve stem and valve seat corrosion.

Repair hidden waste from failed shower diverter valves that cause a portion of the water to be dumped at a user's feet. This leakage is usually not reported to maintenance teams.

Reduce hot water temperature. Temperatures can be safely reduced to 140°F (60°C) for cleaning and laundering.

Install quality low-flow fixtures. Good-quality low-flow showerheads and faucets provide performance almost indistinguishable from that of older fixtures; avoid inexpensive models or pressure-reducing inserts that provide unsatisfactory shower performance.



Setting the water temperature too low can cause problems. Reducing the hot water set-point below 120°F (49°C) to save energy may allow *Legionella* bacteria to grow inside domestic hot water tanks.

Contacts

The FEMP Help Desk at (800) DOE-EREC (363-3732) can provide many publications about energy-efficient water heating.

5.3.1 Heat-Recovery Water Heating

Heat recovery is the capture of energy contained in fluids or gases that would otherwise be lost from a facility. Heat sources may include heat pumps, chillers, steam condensate lines, hot air associated with kitchen and laundry facilities, power-generation equipment (such as microturbines or fuel cells), and wastewater drain lines.

Opportunities

There are two basic requirements for heat-recovery water heating: (1) hot water demand must be great enough to justify equipment and maintenance costs, and (2) the waste heat temperature must be high enough to serve as a useful heat source. Large facilities such as hospitals and military bases often have the perfect mix of waste heat and demand for hot water to effectively use waste-heat-recovery systems for water heating. Consider heat-recovery water heating whenever adding or replacing large heating or air-conditioning equipment. For example, double-bundle chillers can easily provide for the recovery of heat normally lost to a cooling tower. The simplest heat-recovery water preheaters can even work with small commercial kitchens and housing units.

Technical Information

How waste heat is captured and utilized depend upon the temperature of the waste heat source. Where water temperature of 140–180°F (60–82°C) is required, waste heat sources with higher temperatures should be used. Lower-temperature sources, such as hot kitchen air or drainline water, may require mechanical systems to concentrate the heat or supplemental heating using another fuel (i.e., the waste heat serving to *preheat* the water).

Hot gas heat exchangers. The refrigeration cycle of an air conditioner or heat pump provides an opportunity to recover heat for water heating. HVAC compressors concentrate heat by compressing a gaseous refrigerant. The resultant superheated gas is normally

pumped to a condenser for heat rejection. However, a hot-gas-to-water heat exchanger may be placed into the refrigerant line between the compressor and condenser coils to capture a portion of the rejected heat. In this system, water is looped between the water storage tank and the heat exchanger when the HVAC system is on. Heat pumps operating in the heating mode do not have waste heat because the hot gas is used for space heating. However, the heat pump system can still heat water more efficiently than electric resistance heating.

Double-bundle condensers. Some chillers have condensers that make it possible to heat water with waste heat recovery. Double-bundle condensers contain two sets of water tubes bundled within the condenser shell. Heat is rejected from the system by releasing superheated gas into the shell and removing heat as the refrigerant condenses by one of two methods. During the heating season, water pumped through the “winter bundle” absorbs heat that can be used for water heating or heating the perimeter of the building. During the cooling season, water pumped through the “summer bundle” rejects heat to the cooling tower after hot water needs are met.

Heat from engines. Heat exchangers can be placed on exhausts of reciprocating engines and gas turbines to capture heat for water heating or steam generation. Water jackets may also be placed on engines in order to capture heat from the engine and exhaust in series. Some of this equipment also acts as a silencer to replace or supplement noise-reduction equipment needed to meet noise-control requirements. Systems for domestic heating are unpressurized, but temperatures above 210°F (99°C) are possible with pressurized systems. Designers must be careful that the pressure drop is less than the back pressure allowed by the engine manufacturer.

Waste heat from electrical power generation can also be used for water heating. With fuel cells and microturbines beginning to be used for distributed power generation in buildings, for example, there are opportunities to recover the waste heat. See *Section 5.8.8 – Combined Heat and Power*.

Heat from boiler flues. Hot flue gases from boilers can provide a source of waste heat for a variety of uses. The most common use is for preheating boiler feed water. Heat exchangers used in flues must be constructed to withstand the highly corrosive nature of cooled flue gases.



Source: WaterFilm Energy, Inc.

The gravity film exchange (GFX) drainline heat exchangers—technology developed under a DOE grant—make sense in facilities with significant water heating loads, such as kitchens, laundromats, prisons, and military barracks. The system shown above is being installed in a hotel.

Steam condensate heat exchangers. Buildings with steam systems for space heating or kitchen facilities may recover some of the heat contained in hot condensate. Condensate is continuously formed in steam systems when steam loses heat in the distribution lines or when it performs work. A condensate receiver reduces steam to atmospheric pressure to allow reintroduction into the boiler. Condensate heat for heating water can be captured by a heat exchanger located in the condensate return before the receiver.

Heat pump water heaters. Rooms containing laundries and food preparation facilities are often extremely hot and uncomfortable for staff. Heat from the air can be captured for heating water by using a dedicated heat pump that mechanically concentrates the diffuse heat contained in the air. These systems are discussed in *Section 5.3 – Water Heating*.

Refrigeration equipment. Commercial refrigerators and freezers may be installed with condensing units at one location. This will enhance the economic feasibility of capturing heat from hot refrigerant gases for water heating.

Drainline heat recovery. Energy required to heat domestic water may be reduced by preheating with waste heat from drainlines. Kitchens and laundries offer the greatest opportunities for this type of heat recovery since water temperatures are fairly high and schedules are predictable. Drainline-heat-recovery systems can also work in group shower facilities (dormitories, barracks, prisons, etc.) and in residential housing units. The simplest such system has a coil of copper pipe wrapped tightly around a section of copper drainline. Cold water flowing to the water heater flows through this coil and is preheated whenever hot water is going down the drain. More complex systems with heat exchangers within the drainline must be designed to filter out waste materials or provide back-flushing to remove sediment that could cause clogging. It is also necessary to ensure that potable water is not fouled by the wastewater.

References

“Heat Exchangers in Aggressive Environments,” Center for the Analysis and Dissemination of Demonstrated Energy Technologies (CADDET), Analysis Series #16, 1995.

Vasile, C. F., “Residential Waste Water Heat Recovery System: GFX,” Center for the Analysis and Dissemination of Demonstrated Energy Technologies (CADDET), No. 4, December 1997.

Heating water using the sun's energy is practical in almost any climate. Although solar systems can meet the total hot water demand in many regions of the United States during summer months, supplemental water heating is often required in winter.

Opportunities

Many people assume that solar water heating is an option only in extremely sunny or warm climates. That is not the case. In fact, a solar water heating system might be more cost-effective in New Hampshire than in Arizona—depending on the cost of the energy being replaced. Solar water heating is easiest to justify economically when it is replacing electric water heating and when hot water demand is both high enough to justify the initial equipment investment and fairly constant throughout the week. Good candidates are laundries, hospitals, dormitories, gymnasiums, and prisons. Swimming pools are good warm-season applications—very simple, low-cost systems work very well. While costs will be lowest when solar water heating is installed during initial construction, retrofits onto existing buildings are relatively easy and can generally be done with little disturbance to building occupants.

Technical Information

Solar thermal water heating systems come in various configurations suited for different climate zones and applications. The two basic components are collectors, usually mounted on the roof or ground, and an insulated storage tank. Active systems contain mechanical pumps for circulating the collection fluid, which is either plain water or water containing propylene glycol (nontoxic) antifreeze. Passive systems do not have pumps. The most common configurations of solar water heaters are as follows:

Passive thermosiphoning systems rely on the buoyancy of warm water rising from the collector to the tank, which is always located above the collector. Heat pipes—sealed tubing systems containing refrigerant—can also be used for heat transfer from panel to tank.

Passive integral collector-storage (ICS) systems combine collection and storage. Most common are a series of large-diameter (4-inch/100 mm) copper tubes located within an insulated box with glass cover plate. ICS systems are generally plumbed in-line with the building's tap water, so they are pressurized. Potable water enters at the bottom of the ICS collector, and warm water is drawn from the top. With ICS systems, roof structures must be strong enough to support the weight of water-filled collector tanks.

Active direct or “open-loop” systems are simple, very efficient, and suitable for mild and moderate climates with good water quality. In direct systems, potable water is pumped through the collector. Often, photovoltaic- (PV-)powered, DC pumps are used, providing a built-in control system—when it is sunny, water is circulated through the collector. Damage to collectors is a concern if water is hard or corrosive. Also, freeze protection is needed. Direct systems are especially applicable to swimming pool heating.

Active indirect or “closed-loop” systems are dependable and suitable for all climates. Indirect systems circulate nontoxic antifreeze (propylene glycol) through the closed loop, which consists of collector, piping, and heat exchanger located at the storage tank. Nontoxic antifreeze in the collector and exposed piping ensures protection from freeze damage, corrosion, and scaling. Like direct systems, indirect systems may use PV-powered pumps; otherwise, differential thermostats are typically used to turn AC pumps on and off.

FREEZE PROTECTION

Freeze protection is an important consideration in all but tropical climates. Four primary strategies are used with active solar water heating:

- **Drainback systems** include a small reservoir into which water is drained from collectors and exposed piping whenever the circulating pump is turned off. This provides reliable freeze protection even when electrical power fails. It also protects the fluid from high temperatures by turning off the pump and draining the collector.
- **Draindown systems** dump water from a collector into a drain when triggered by near-freezing temperatures. They may also be manually drained in case of power failure during freezing. Draindown systems historically have been the least reliable because valves may freeze closed or become clogged with corrosion, preventing drainage.
- **Recirculation systems** utilize warm water from the storage tank to circulate into the collectors during freezing weather. They should be considered only in very mild climates.
- **Indirect systems** are filled with a nontoxic antifreeze solution all the time. They are reliable for use in any climate and are very effective at avoiding freeze damage, though if the pump fails or electricity is lost, the antifreeze may be damaged in the stagnating collector. A heat exchanger is required to heat the potable water.



Photo: Warren Gretz

Solar water heating directly substitutes renewable energy for conventional fossil fuels or electricity. This array of parabolic trough collectors at a prison was paid for through a FEMP Energy Savings Performance Contract or ESPC.

SOLAR COLLECTORS

Three basic types of collectors are used for active solar water heating:

- **Flat-plate collectors** are the most common and generally consist of insulated rectangular frames containing small-diameter, fluid-filled copper tubes mounted on copper or aluminum absorber plates. Selective-surface coatings are applied to the tubing and absorber plates to emit less heat radiation. High-transmission tempered glass covers the absorber.
- **Evacuated-tube collectors** utilize a tube-within-a-tube design similar to a thermos bottle. A vacuum between the fluid-filled inner copper tube (generally with absorber fin) and glass outer tube permits maximum heat gain, minimum heat loss, and very high temperatures.
- **Parabolic trough collectors** focus sunlight onto a tube with selective-surface coating (usually contained within a vacuum tube). These systems tend to be more complex than stationary collectors because they have to track the sun as it moves across the sky, but performance is very good. They are most appropriate for large commercial installations requiring significant quantities of hot water. In addition to providing hot water, they can be used for process heat and absorption cooling. The recent development and commercialization of compound parabolic collectors promises significant improvements in performance. Because the collectors focus sunlight, they are a poor choice for cloudy climates.

Solar systems should be tested and certified by independent groups such as the Solar Rating and Certification Corporation (SRCC) or the Florida Solar Energy Center (FSEC).

Colder climate zones require more collector area and indirect systems with superior freeze-protection capabilities.

Removing trees to provide access to sunlight for solar collectors could be a net energy loser if there is substantially more heat gain through exposed windows and thus increased cooling loads. Site collectors carefully, and prune trees selectively.

At times of the year when collectors harvest sunlight very efficiently, water temperatures may be above 140°F (60°C). Ensure that mixing valves are installed to keep users from being scalded.

On direct systems, collectors may require periodic treatment with a nontoxic solution, such as diluted vinegar, to remove scaling buildup that inhibits heat transfer and efficiency.



The economics of installing solar water heating depend on the cost of the fuels being replaced. Hot water demand, patterns of usage, incoming water temperature, and availability of solar energy are also key considerations. Retrofitting solar water heating into existing buildings is complicated by the need to provide access for running pipes and space in mechanical rooms for larger storage tanks. Solar water heaters typically provide 40–80% of annual hot water needs.

References

“Solar Water Heating,” *Federal Technology Alert*, Federal Energy Management Program, Department of Energy, Washington, DC, September 1995 (also available on the Web at www.eren.doe.gov/femp/).

Contacts

The FEMP Help Desk at (800) DOE-EREC (363-3732) or at www.eren.doe.gov/femp/ can provide technical assistance and information about financing via ESPCs.

Florida Solar Energy Center, 1679 Clearlake Road, Cocoa, FL 32922; 407/638-1000; www.fsec.ucf.edu (Solar Rating and Certification Corporation—same address; 407/638-1537; www.solar-rating.org).

Center for Buildings and Thermal Systems, National Renewable Energy Laboratory, 1617 Cole Blvd., Golden, CO 80401; 303/275-3000; www.nrel.gov/buildings_thermal/.

5.4 Lighting

Lighting accounts for 25% of the electricity used in the Federal sector. If advanced lighting technologies and designs were implemented throughout the Federal sector, electricity use for lighting would be cut by more than 50%, electrical demand dramatically reduced, and working environments significantly improved. Lighting power densities of 2.5 watts per square foot (typical for many office buildings) can be reduced to 1 watt per square foot or even less in new buildings and major renovation by (1) optimizing the use of natural daylighting; (2) installing modern, efficient luminaires; (3) replacing ballasts and lamps with modern components; (4) replacing incandescent lamps with compact fluorescent lamps (CFLs); (5) replacing mercury vapor lamps with metal halide or fluorescent lamps (including new T-5s); (6) implementing task lighting strategies; and (7) installing state-of-the-art lighting controls.

Opportunities

Consider making it a very high priority to retrofit the lighting system whenever undertaking renovations or new additions. Even reconfiguring workspaces (adding partitions, for example) provides an opportunity to upgrade the ceiling lighting system and add task lighting where appropriate. If the HVAC system is being upgraded or replaced, that presents another opportunity to upgrade the lighting system—in fact, the reduced cooling loads that can be achieved with state-of-the-art lighting may enable significant downsizing of chillers and even pay the full first-cost of the lighting improvements while ensuring dramatic savings in ongoing energy use. Whenever possible, incorporate daylighting strategies into a building (new or existing) and integrate the electric lighting system appropriately (see 4.1.2 – *Daylighting Design*). Replacing incandescent wall sconces, downlights, decorative pendants, and exit sign lighting with CFL units (or, in the case of exit signs, with light-emitting diode [LED]-lit units) will not only save a considerable amount of energy, it will also significantly reduce labor costs associated with relamping.

Technical Information

LIGHTING DESIGN ASSISTANCE

Designing a lighting system that provides visual comfort at low energy cost is more of an art than generally thought. Hire a lighting designer for both new building design and lighting retrofit projects. The designation “LC” after a consultant’s name indicates “lighting certified” by the National Council for the Qualification of Lighting Professionals—a certification program supported by DOE. With lighting retrofit projects, the lighting designer should inventory the age and type of lighting equipment, examine visual tasks in the building and changes that have occurred (such as increased use of computers), and interview workers about their satisfaction with the lighting.

DESIGN STRATEGIES FOR IMPROVED LIGHTING

- Refer to the *IESNA Lighting Handbook – 9th Edition* (2000) for lighting quality and quantity recommendations—match lighting to tasks. An inexpensive light meter (less than \$200) can help determine whether needs are being met in existing work spaces.
- Consider brightening interior surfaces—the perception of spaciousness and the relative “cheeriness” of spaces is directly related to wall and ceiling brightness.
- Use a combination of direct and indirect lighting to minimize harsh contrasts, which can be uncomfortable and tiring.
- Consider reducing ambient light levels (or relying on natural daylight) and supplying task lighting where the light is needed.

LIGHTING EQUIPMENT SELECTION

- Choose fixtures (luminaires) that efficiently deliver light and are well suited to the expected tasks (see 5.4.1 – *Linear Fluorescent Lighting* for more on fixture selection).
- Depending on the ceiling fixtures selected, some additional illumination on walls and ceilings may be needed to achieve adequate *vertical surface brightness*. This is particularly important with parabolic fixtures (see *Section 5.4.1*). Wall and ceiling illumination can be provided with luminaires that deliver some of their light upward, wall-wash sconces, and daylighting.

- Select fluorescent lamps with a high color rendering index (CRI) and color temperature well suited to the space and tasks.
- Install lighting control systems that will dim or turn off lights when the illumination is not needed—either because people have left the space or because of adequate daylighting. Provide manual dimming control, especially in small offices.

TOOLS TO ASSIST IN LIGHTING DESIGN AND PRODUCT SELECTION

(see References for information on accessing the Building Energy Tools Directory)

- **Commercially available software tools**, including *Lumen-Pro*, *Radiance*, and *LightScape*, are a tremendous help in lighting design.
- **FEMP's Federal Relighting Initiative** is a program that provides facility managers with lighting evaluation tools and lighting retrofit information.
- **Lighting Technology Screening Matrix (LTSM)** software evaluates different lighting technologies on a per-fixture basis. The algorithms are based on lumen equivalents, but the user can adjust for areas that are overlit or underlit. The LTSM program is primarily a financial tool that generates a list of potentially cost-effective lighting retrofits.
- **Lighting Systems Screening Tool (LSST)** software allows managers to evaluate system retrofits on a facility-wide basis. It can either make assumptions about existing lighting for a first cut or allow more precise evaluation using actual data entered for the facility.
- **The Federal Lighting Expert (FLEX)** is an expert system that can assist facility managers in optimizing lighting retrofit projects. It is user-friendly, can be used by nonexperts, and has a product database with performance specifications and cost information.
- **The Master Specifications (Version 2.03)** is a generic specification for energy-efficient lighting systems targeted at Federal facilities. It addresses lamps, ballasts, reflectors, and luminaires. Parts of the specification can be copied verbatim to assist in the preparation of technical specifications for specific projects.



Mercury is present in all fluorescent and mercury vapor lamps, and polychlorinated biphenyls (PCBs) are in many older fluorescent ballasts. These materials can be extremely hazardous to human health and the environment and should be disposed of only through specialized recycling or hazardous disposal facilities. Never discard lamps or ballasts that do not carry labels "No PCBs" with ordinary waste.

References

Advanced Lighting Guidelines, Report Number DOE/EE-0008, NTIS Order Number DE94005264, U.S. Department of Energy, Washington, DC, 1993. Provides acceptable lighting levels for various applications.

ASHRAE Standard 90.1, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Atlanta, GA; www.ashrae.org.

IESNA Lighting Handbook – 9th Edition, Illuminating Engineering Society of North America, New York, NY, 2000; (212) 248-5000; www.iesna.org.

Contacts

The FEMP Help Desk at (800) DOE-EREC (363-3732) has information about the Federal Relighting Initiative, training courses devoted to lighting technologies and techniques, and software; see also the lighting information on the Web at www.eren.doe.gov/femp/.

ProjectKale software is available from the EPA Green Lights Hotline: (202) 775-6650.

DOE's Building Energy Tools Directory offers information on over 200 software tools covering lighting and other topics. Many of these tools are free or accessible online; www.eren.doe.gov/buildings/tools_directory.

The National Lighting Product Information Program (NLPIP) of the Lighting Research Center at Rensselaer Polytechnic Institute offers independently evaluated product information, including manufacturer-specific test results on thousands of lamps, fixtures, ballasts, and controls; www.lrc.rpi.edu.

Association of Lighting and Mercury Recyclers, 2436 Foothill Blvd., Suite K, Calistoga, CA 94515; (707) 942-2197.

5.4.1 Linear Fluorescent Lighting

In U.S. commercial buildings, lighting accounts for 23% of total energy consumption (1995) and 46% of total electricity consumption. The vast majority of interior lighting in commercial buildings is provided with linear fluorescent fixtures (luminaires) and lamps. There have been significant improvements in fluorescent lighting technologies in recent years, including new higher-quality lamps, improved electronic ballasts, more advanced luminaires, and better controls.

Opportunities

Whenever an interior space is being renovated or reconfigured, the lighting should be carefully examined. Changing the location of workspaces, adding or moving interior partitions, replacing ceilings, and even painting walls will alter the characteristics of, and provide an opportunity for upgrading, existing lighting. Substantial savings are often possible with reliance on task lighting where existing, uniformly lit spaces include defined task areas. When specifying systems for a new space, always require lighting to be efficient, and look for opportunities to integrate daylighting strategies.

Technical Information

Fluorescent lighting is the best source for most Federal lighting applications because it is efficient and can be switched and controlled easily. Modern linear fluorescent lamps have good color rendering and are available in many styles. Lamps are classified by length, form (straight or U-bend), tube diameter (T-8, T-5, etc.), wattage, pin configuration, electrical type (rapid- or instant-start), color rendering index (CRI), and color temperature. When specifying a lighting system, be sure that the lamp and ballast are electrically matched and the lamp and fixture optically matched.

Fluorescent lamp diameters are measured in 1/8-in. increments—T-12s are 12/8 in. or 1-1/2 in. in diameter; T-8s are 1 in. Most fluorescent lamps are straight, though T-8s and T-5s are also available in U-bend or

folded configurations. (Until the late 1990s, T-5s were only available folded, but straight-tube T-5s are becoming more common.) Straight-tube fluorescent lamps are most often used in 1x4-, 2x4-, and 1x8-ft luminaires; folded lamps are used for smaller, square fixtures—1x1s or 2x2s. Typical linear fluorescent lamps are compared in the table below; note that efficacy (lumens per watt) is higher with smaller-diameter lamps.

Color rendering of fluorescent lamps is very important. Modern, efficient fluorescent lamps use rare-earth phosphors to provide good color rendition. The color rendering index describes how a light source affects the appearance of a standardized set of colored patches under standard conditions. A lamp with a CRI of 100 will not distort the appearance of the patches in comparison to a reference lamp, while a CRI of 50 will significantly distort colors. T-8 and T-5 lamps are available only with high-quality phosphors that provide CRIs greater than 80. The minimum acceptable CRI for most indoor applications is 70; levels above 80 are recommended.

Color temperature influences the appearance of luminaires and the general “feel” in the space. Low color temperature (e.g., 2,700K) provides a warm feel that is similar to light from incandescent lamps; 3,500K provides a balanced color; and 4,100K emits “cooler” bluish light. Standardizing the color temperature of all lamps in a room or facility is recommended.

Specify electronic ballasts with all linear fluorescent lighting. These are significantly more energy-efficient than magnetic ballasts and eliminate the hum and flicker associated with older fluorescent lighting. Dimming electronic ballasts are also widely available.

Select luminaires that are appropriate for the tasks being performed. Reflectorized and white industrial fixtures are very efficient and good for production and assembly areas but usually inappropriate for office applications. Lensed fluorescent fixtures (“prismatic lens” style) typically result in too much reflected glare off computer screens to be a good choice for today’s electronic office. In areas with extensive computer use, common practice is to install “parabolic” luminaires, which minimize high angle light that can cause reflected glare in computer screens; however, these may result in unpleasant illumination with dark ceilings and walls. Instead, for tall ceilings—over 9 ft (2.7 m) in height—use direct/indirect pendant luminaires. For lower ceilings—8 ft 6 in. (2.6 m)—consider parabolic luminaires with semi-specular louvers and provide separate wall-washing to minimize high contrast.

Do not select luminaires based solely on efficiency. Some of the highest-efficiency luminaires have inferior photometric performance. The most effective

COMPARISON OF FLUORESCENT LAMPS

Lamp Type	T-12	T-12 ES	T-8	T-5*
Watts	40	34	32	54
Initial lumens	3,200	2,850	2,850	5,000
Efficacy (lm/W)	80	84	89	93
Lumen depreciation**	10%	10%	5%	5%

* High-output T-5 in metric length
** Change from “initial lumens” to “design lumens” Source: Philips Lighting

$$\text{Luminaire Efficiency Rating} = \frac{\text{Fixture efficiency} \times \text{Lamp lumens} \times \text{No. of lamps} \times \text{Ballast factor}}{\text{Input watts}}$$

luminaires are usually not the most efficient, but they deliver light where it is most needed and minimize glare. The new Luminaire Efficiency Rating (LER) used by some fluorescent fixture manufacturers makes it easier to compare products. Since the LER includes the effect of the lamp and ballast type as well as the optical properties of the fixture, it is a better indicator of the overall energy efficiency than simple fixture efficiency. An LER of 60 is good for a modern electronically-ballasted T-8 fluorescent fixture; 75 is very good and close to “state-of-the-art.”

Provide for control of light levels. One option is dual-level lighting (tandem or split-wiring) so that a 50% lighting level can be obtained when desired (check local codes). Another option is either automated or manual dimming using special ballasts and controls. Photocell-controlled dimming is particularly important if there is a significant daylighting component to the lighting design. See 5.4.4 – *Lighting Controls*.

Replace 4-lamp T-12 luminaires with half the number of T-8 lamps (usually in the outer lamp positions) and upgrade to electronic ballasts. A lighting designer should be consulted to evaluate the effectiveness of this strategy and the various alternatives.

Avoid using retrofit reflectors that fit into existing luminaires. Except in one- and two-lamp industrial strips, the white-painted inner surfaces of luminaires serve as very effective reflectors. Because highly reflective specular reflectors often produce striated patterns on surfaces being lit and cause light to “dump” beneath the fixture, they can produce worse lighting than the original diffuse reflectors.

Avoid inappropriate retrofits. If original lighting conditions are poor and cause visual discomfort or ineffective light use because of poorly placed fixtures, conversion to T-8s alone will not provide a satisfactory solution. Complete lighting redesign, retrofit, and even complete ceiling replacement to accommodate new lighting may be necessary. Any lighting retrofit should include a lighting design analysis.

Avoid high-intensity discharge lighting, even with high ceilings. Fluorescent lighting is generally far superior, less costly, easier to control, and provides better light quality than even metal halide. For very high ceilings (e.g., in gymnasiums), new high-bay luminaires using multiple T-5 lamps are proving highly successful. In most high-ceiling areas, try to provide a mix of lighting types, including indirect uplighting, downlighting, wall sconces, decorative pendants in lobby areas, etc.

Always transport and store fluorescent lamps horizontally to prevent phosphorus coatings from settling to the ends of the tubes.

Recycle fluorescent lamps and ballasts. All fluorescent lamps contain mercury, which should be kept out of landfills and municipal incinerators. Phosphor coatings also contain harmful materials that should be kept out of the waste stream. Before 1979, nearly all ballasts for fluorescent lamps contained PCBs (polychlorinated biphenyls), which are highly toxic chemicals that bioaccumulate in biological systems through the food chain. Specialized lamp and ballast disposal firms can thermally destroy PCBs and recover mercury from old lamps (see listing below).



In specifying fluorescent lamps, look for low-mercury products that will cause less of this toxic metal to enter the environment if disposal is not handled properly.

References

IESNA Lighting Handbook – 9th Edition, Illuminating Engineering Society of North America, New York, NY, 2000; (212) 248-5000; www.iesna.org.

Lighting guide specifications for lamps, ballasts, luminaires, and reflectors have been developed under the FEMP Federal Relighting Initiative. Software to assist in system selection and design also is available from the FEMP Help Desk at (800) DOE-EREC or from the FEMP Web site at www.eren.doe.gov/femp/.

The *Lighting Upgrade Manual* may be downloaded at www.epa.gov/docs/CGDOAR/gcd_pubs.html#glpubs.

Lighting Waste Disposal (6202J), U.S. Environmental Protection Agency, Office of Air and Radiation, 1994.

Electric Utility Guide to Marketing Efficient Lighting, Western Area Power Administration, Golden, CO, 1990; (303) 231-7504.

Contacts

EPA Green Lights and ENERGY STAR® Programs Hotline: (202) 775-6650.

The National Lighting Product Information Program (NLPIP) of the Lighting Research Center at Rensselaer Polytechnic Institute offers independently evaluated product information, including manufacturer-specific test results on thousands of lamps, fixtures, ballasts, and controls; www.lrc.rpi.edu.

Association of Lighting and Mercury Recyclers, 2436 Foothill Blvd., Suite K, Calistoga, CA 94515; (707) 942-2197.

5.4.2 Electronic Ballasts

Electronic ballasts (sometimes called solid-state ballasts) are efficient replacements for standard magnetic ballasts. Since the lamp and ballast form a system, lamps are generally changed at the same time ballasts are upgraded. Used with the proper fluorescent lamps, electronic ballasts provide energy-efficient lighting while eliminating the flicker, hum, and poor color rendering associated with older fluorescent lighting. Electronic ballasts capable of driving up to four lamps are available. These will continue to drive three lamps even after one has failed. Some electronic ballasts can also be dimmed, although this generally requires an additional low-voltage control circuit.

Opportunities

Investing in new fixtures with electronic ballasts should be considered if the existing lighting system (1) is old and prone to failure; (2) is inappropriate for current and future use; (3) is kept on for many hours per day; (4) produces flicker, glare, or other discomforts for occupants; (5) causes problems with sensitive electronics in the facility; or (6) produces lighting levels that are either too low or too high. All the fixtures in an entire area are often redone at the same time to save on installation costs and to achieve an integrated design. However, if the original fixtures are in good shape and well suited to an area's needs, it may be possible to replace just the ballasts and lamps.

Technical Information

In 1988, only 1% of the 75.7 million ballasts shipped in the United States were electronic; in 1998, 38% of the 104 million ballasts shipped were electronic. In 2000, DOE issued a new ballast standard that will require high-efficiency electronic ballasts in all new



Ballasts manufactured before 1979 probably contain polychlorinated biphenyls. PCBs are hazardous because they cause cancer, do not readily break down in the environment, and bioaccumulate in plant and animal food chains. PCB-containing ballasts must be disposed of properly in a hazardous-waste or ballast-recycling facility. Ballast-recycling firms salvage reusable metals, reducing the volume of PCB-containing material for disposal.

commercial fixtures manufactured after April 1, 2006, and electronic ballasts for most replacement applications after July 1, 2010.

Ballast specifications include:

- Input voltage (usually 277 or 120 VAC)
- Number and type of lamps powered per ballast
- Power factor
- Total harmonic distortion (THD)
- Circuit type (instant-start or rapid-start; series or parallel operation)
- Lamp operating frequency (kHz)
- Ballast factor (BF)
- Ballast efficacy factor
- Minimum starting temperature
- Rated life in hours

Guidance for specifying these and other parameters is available from the National Lighting Product Information Program of the Lighting Research Center.

Instant-start electronic ballasts are slightly more efficient than rapid-start ballasts, but they result in some degradation of lamp life (instant-start operation generally reduces lamp life by about 25%—typically yielding a 15,000-hour life instead of 20,000 hours). Rapid-start operation is usually required for reduced-output ballasts and dimming ballasts. Parallel operation is generally preferable to series operation. If one lamp fails with a parallel-circuit ballast, the other lamp(s) will continue to operate. With series operation, neither lamp will operate if one fails.

Dimming is available as an option for some electronic ballasts. These are always of the rapid-start type, and the dimming ballast will generally have two extra wires for a low-voltage control signal (typically 0–10 VDC). By connecting a simple wall-mounted potentiometer to the low-voltage control wiring, an occupant can control light levels between about 10% (depending on product) and 100% of maximum light output. Alternatively, the control wires can be connected to a ceiling-mounted photocell that adjusts the electric light level to supplement available daylight, thus saving energy (see *Section 5.4.4 – Lighting Controls*).

Power factor indicates how effectively the input power and current are converted into usable watts of power delivered to the ballast. High-power-factor ballasts reduce current loads on building wiring and transformers. Specify high-power-factor ballasts (power factors of 0.90 or higher).

Ballast factor quantifies the light-producing ability of fluorescent lamps relative to a laboratory reference ballast. For electronic ballasts, the BF can range from about 0.7 to 1.5. It usually makes sense to specify a BF between 0.85 and 1.0 to maximize light output from a specific lamp/ballast combination without overdriving the lamps (which can shorten lamp life). A ballast may have one BF for standard lamps and another for energy-efficient lamps.



One way to significantly reduce energy costs in overlit spaces is to replace existing magnetic ballasts with reduced-output T-8 electronic ballasts (with a BF of 0.70) and relamp with T-8 lamps. Although the T-8 lamp output will be reduced 30% from the rated value, the new levels will be more appropriate, and more energy is saved than with “normal” BF ballasts.

Ballast efficacy factor is the ratio between light output (lumens) of lamps operating on a ballast divided by the input wattage to the ballast. Ballast efficacy factor is useful in comparing ballasts within a given type of lighting system—for example, for the class of 4-foot fluorescent lamps.

Total harmonic distortion defines the effect a device has on the ideal electrical sinusoidal waveform. Harmonics within a facility can cause problems with electronic and communications equipment, can overload transformers, and can cause unexpected loading of the neutral in a three-phase system. Although other equipment can be responsible for harmonic distortion, ballasts are often blamed for these power-quality problems. To avoid problems, specify ballasts with a THD of 20% or less. Ballasts with a THD of 5% or less are available for areas with sensitive electronic equipment or other special needs.

Specify electronic ballasts with the following performance, unless there is a reason to do otherwise:

- Ballast factor: 0.85 to 1.0
- Power factor: greater than 0.90
- Total harmonic distortion: less than 20%

Ballasts capable of operating four lamps can be wired to lamps in several fixtures, saving both initial equipment costs and operating costs.



Many ballasts have a minimum starting temperature rating of 50°F (10°C), and may not be suitable for unconditioned locations. Other ballasts offer low-temperature starting down to 0°F (-17°C).

References

Guide to Specifying High-Frequency Electronic Ballasts, November 1996, and *Electronic Ballasts – Specifier Report*, May 2000, National Lighting Product Information Program (see contacts below). Guides available as downloadable pdf files: www.lrc.rpi.edu/NLPIP.

Lighting Waste Disposal (EPA 420-R-94-004), Office of Air and Radiation, U.S. Environmental Protection Agency, 1994.

Energy-Efficient Lighting Catalog, Defense Logistics Agency, 1996. A good source of equipment information.

Lighting Technology Atlas, E Source, Inc., Boulder, CO, 1997; (303) 440-8500; www.esource.com.

Contacts

National Lighting Product Information Program, Lighting Research Center, Rensselaer Polytechnic Institute; (518) 276-8716; www.lrc.rpi.edu/NLPIP (manufacturer-specific ballast data available online).

FEMP’s ballast specifications are available from the FEMP Help Desk at (800) DOE-EREC (363-3732).

EPA ENERGY STAR® Buildings/Green Lights Program Customer Service Center has information about ballast disposal at (202) 775-6650; www.epa.gov/energystar.

Defense Logistics Agency, Defense Supply Center, Richmond, VA; (800) DLA-BULB; www.dgsc.dla.mil.

Association of Lighting and Mercury Recyclers, 2436 Foothill Blvd., Suite K, Calistoga, CA 94515; (707) 942-2197.



To avoid significantly reducing ballast life, promptly replace fluorescent lamps that strobe or have blackened ends.

Compact fluorescent lamps are energy-efficient, long-lasting substitutes for incandescent lamps. Introduced in the early 1980s, these lamps use only one-quarter to one-third as much energy to produce the same light output as incandescents. Because they last up to 13 times longer than incandescent lamps, CFLs also provide an attractive return on investment.

Opportunities

Compact fluorescent lamps can be substituted for incandescent lamps in nearly all applications where incandescents are commonly used—except where directional accent lighting is required (for example, where artwork needs to be illuminated). Incandescent lamps used the most hours per day are the highest-priority candidates for replacement with CFLs; replacement can easily be justified because of the energy savings possible with any lamp used more than an hour a day. It is best to replace incandescent fixtures with those optically designed and hard-wired for CFLs. Alternatively, screw-in CFLs with integral ballasts can often be swapped for incandescent lamps, though this is not generally recommended for recessed downlights. CFLs are particularly appropriate for wall sconces, low ceiling downlights (ceilings up to 9 ft or 2.7 m), wall-washers, and decorative pendants.



Retrofit lamps that contain the lamp, ballast, and screw base all in one unit are widely available. As a rule, however, these units should be avoided for several reasons:

- They are often replaced by incandescent lamps when they fail, negating savings.
- The geometry of the bulky retrofit often makes it difficult to position the lamp in the fixture where it can achieve the best lighting output.
- The ballasts can outlast the lamps by a factor of five or more, and disposing of the ballast with the lamp is thus wasteful.
- Though this varies according to the manufacturer and the configuration, heat from an integral ballast does not dissipate well, and thus both lamp life and ballast life are reduced.
- It is easier for these relatively expensive retrofits to be stolen than for a whole new fixture to be removed.

Technical Information

Compact fluorescent lamps have excellent color rendition and are available in a wide variety of sizes, shapes, and wattages. They are suitable both in new buildings and in renovations and are most appropriate for general (as opposed to directional) lighting. For dimming applications, four-pin CFLs are required. As a rule of thumb, 1 watt of compact fluorescent can replace 3 to 4 watts of incandescent lighting—e.g., a 60-watt incandescent lamp can be replaced by a 15- to 20-watt compact fluorescent lamp. The light output of fluorescent lamps is sensitive to both temperature and burning position, while that of an incandescent bulb is not—so in some fixtures CFLs will perform differently than in others. Very-low-wattage CFLs (below 13 watts) have lower efficacy than higher-wattage CFLs, poor power factor, and lower-quality phosphors; they are generally available only with magnetic ballasts.

Fixtures for compact fluorescent lamps come in a variety of styles to meet many lighting situations. Fixtures hard-wired for CFLs contain ballasts required to operate the lamps and special sockets to hold the lamps in the proper position. With this modular configuration, when the lamps fail, they can be replaced without having to replace the longer-life ballasts as well. CFLs are also available with integral ballasts and screw-base sockets for use in fixtures designed for standard incandescent lamps. See the cautionary note on this page regarding retrofit lamps.

A lighting survey is the first step in planning to replace incandescent lamps with CFLs. Although not every incandescent lamp has a compact fluorescent equivalent, facility managers can establish a plan to gradually change over to these more cost-effective alternatives. Software such as the *Lighting Technology Screening Matrix* (LTSM) and the *Lighting System Screening Tool* (LSST) can help with planning and a financial assessment. See *Section 5.4* for a description of these tools and how to obtain them.

Rated lamp life of CFLs is typically 10,000 hours, or 5 to 13 times longer than that for incandescent lamps. Long life helps provide a favorable life-cycle cost and labor savings for lamp replacement. However, lamp life varies considerably by manufacturer (see NLRIP Specifier Report: Screwbase CFLs) and is sensitive to how often the lamp is switched on and off. Burning life is longer if lamps burn continuously or for many hours at a time; lamp life can be much shorter if the lamp is switched on and off frequently, so be careful about using CFLs in fixtures on motion sensors that are activated frequently.



Source: Pacific Northwest National Laboratory

The new twisted-tube compact fluorescent lamps are nearly as small as standard lightbulbs.

Overlighting is common, so one-for-one replacement of incandescent lamps with their CFL equivalents may result in overlit conditions. As part of a lighting survey, it is important to determine the lowest wattage lamp that can be used for the application.



Replacing incandescent fixtures with compact fluorescent fixtures typically achieves a 35% annual return on investment.

References

Electric Utility Guide to Marketing Efficient Lighting (ref. contract DE-AC65-86WA00467), Western Area Power Administration, Golden, CO, 1990.

Contacts

Defense Logistics Agency, Defense Supply Center, Richmond, VA; (800) DLA-BULB; www.dgsc.dla.mil.

EPA Green Lights and ENERGY STAR® Programs Hotline: (888) STAR-YES.

The National Lighting Product Information Program (NLPPI) of the Lighting Research Center at Rensselaer Polytechnic Institute offers independently evaluated product information, including manufacturer-specific test results on thousands of lamps, fixtures, ballasts, and controls; www.lrc.rpi.edu.

WHERE CFLS ARE NOT AS APPROPRIATE

Where CFLs Should Be Avoided	More Appropriate Solution
Applications where tight beam control is required	Provide low-wattage reflector-type tungsten halogen lighting.
Outdoor lighting in very cold areas	Many CFL ballasts will not operate below about 32°F (0°C). Even when low-temperature ballasts are used, lamps will not reach full brightness for several minutes in cold weather.
High-bay lighting—ceiling higher than 20 ft (6 m)	Specify linear fluorescent lighting, including high-bay luminaires using tightly packed T-5 lamps.
Medium-bay lighting—ceiling 12 to 20 ft (3.7 to 6 m)	Use a combination of direct and indirect lighting with linear fluorescents.
Exposed-lamp applications with high-wattage CFLs	High-wattage CFLs are very bright if exposed; provide some type of shielding.
Where frequent switching is required, such as with motion sensors	Frequent on-off switching will reduce lamp life of CFLs; incandescents (including halogen lamps) may be a better option.
Exit sign illumination	Replace incandescent or fluorescent lamps with LED retrofits, or replace exit signs with LED models.



Look for applications with long burn hours. Interior and exterior hallways and walkways provide excellent opportunities for cost-effective replacements with CFLs because these locations typically have long burn hours. Sconces containing CFLs make excellent retrofit fixtures for these applications. Make sure the lamp does not extend below the bottom of the luminaire.



The National Electric Code forbids the use of incandescent fixtures in small clothes closets and other locations where the heat from incandescent lamps can be a fire hazard. CFLs can be used in many of these applications due to their low heat generation.



When replacing incandescent lamps in recessed cans with screw-in CFLs, it is often best to use a CFL with a built-in reflector or a retrofit CFL reflector fixture.



Some lamps take a second to turn on and flicker initially; others do not. Consult your supplier about this issue.

5.4.4 Lighting Controls

Lighting controls enable building occupants or building managers to modify illumination levels to meet task and comfort requirements while minimizing unneeded or wasted lighting energy use. A well-designed lighting control system has the potential to reduce lighting energy use by 30–50%. Electric lighting can be controlled by giving occupants manual control over their personal lighting, by automatically controlling light levels based on occupancy or daylight levels, or by a combination of these strategies. Occupancy sensors can turn off lighting when no one is in the area. Daylight controls are better handled with dimmers than with on/off switches.

Opportunities

Buildings where banks of electric lights are on all day, irrespective of the amount of natural daylight and occupancy, are excellent candidates for retrofitting with more sophisticated lighting controls. Rooms with window walls but no ability to control banks of luminaires along the windows are also good candidates for better controls. Whenever a building is being renovated or remodeled to the extent that the lighting is being reconfigured in any way (see *Section 5.4 – Lighting*), be sure to consider lighting controls as well. These can be combined with daylight dimming controls that set an upper lighting limit and with occupancy sensors that turn off the lights when no one is in the area. Use automatic daylight dimming or on/off controls for common and public areas. Use occupancy sensors in all areas of the building for maximum energy savings.

Technical Information

Many types of controls not only give occupants control over their space but also respond to daylighting and occupancy through dimming and on/off controls. The key to a successful lighting control project is selecting the correct system to give occupants “control” over their lighting, as opposed to a system that takes away that control. Inappropriate lighting controls may be overridden, which results in loss of all potential energy savings.

MANUAL DIMMING

Manual dimming is ideal for individual offices, conference rooms, and classrooms. Lighting levels can be dimmed by the occupants according to the tasks and appearance of an area. Psychologically, manual dimming is the most successful type of control because occupants can vary their own lighting levels. Fluorescent dimming ballasts can lower the lighting power to as little as 1–10%, depending on the ballast type. Every time the lights are dimmed, energy is saved.

DAYLIGHT CONTROLS

Automated daylight dimming is an important lighting control strategy in spaces where there is a significant amount of natural light but where turning electric lights off altogether would be inappropriate. Thus, it is a useful strategy in perimeter areas of large open offices, lobby areas, and employee lounges. Dimming electronic ballasts reduce or increase the light output gradually as natural light level changes, almost imperceptibly. Where daylight is adequate and the light source is not easy to see from normal viewing angles, lighting can be turned off with a photosensor control.

OCCUPANCY SENSORS

Occupancy sensors (infrared, ultrasonic, and combination) provide an ideal way of turning lights off when no one is in the area. In order to avoid nuisance on/off



High-quality occupancy sensors and other types of lighting controls like these are now readily available from a number of manufacturers.

Photo: The Watt Stopper



Photo: Lutron Electronics Co., Inc.

Customized controls like these are available for controlling not only lighting but also drapes, projector screens, and other electrically operated devices.

trippings, make sure that the occupancy sensor is specified for the type of area and its use. Consult with occupancy sensor control manufacturers to ensure the correct number, type, and mounting of occupancy sensors so they will provide proper coverage and optimal control. Specifics on the various types of occupancy sensors are as follows:

Infrared occupancy sensors are ideal for small enclosed rooms, such as private offices, conference rooms, small supply rooms, classrooms, and other spaces where the sensor has a “line of sight” view to occupants. Infrared sensors pick up small amounts of movement and are reliable in these small, unpartitioned situations. Wall-mounted infrared sensors are the most common.

Ultrasonic occupancy sensors are ideal for large open spaces and areas where partitions are present, such as open offices, large conference rooms, lecture halls, hallways, large lunchrooms, and lobbies. Ceiling-mounted ultrasonic sensors are the most common.

Combination infrared and ultrasonic sensors provide the most reliable system because use of both detection mechanisms overcomes the weaknesses of each.

MANUAL DIMMING/INFRARED COMBINATION

The combination of manual dimming with occupancy sensors is another good option for small offices and conference rooms. One wall-mounted control can provide manual dimming for the occupant and still turn lights off when everyone leaves the room.

POST-OCCUPANCY EVALUATION (FINE-TUNING CONTROLS)

It is important for users to understand how to use dimming and occupancy controls. Correctly setting sensitivities and time delays prevents nuisance on/off trippings. In addition, longer time delays are appropriate for areas that should remain lighted all day long, such as main hallways and busy restrooms, but where lighting should be turned off at the end of the day. Lights can turn on for cleaning crews and employees working in off-hour periods. Both occupancy sensors and daylight sensors need to be adjusted to provide the desired lighting levels.

Contacts

National Dimming Initiative, (847) 390-5136. Industry initiative led by Advance Transformer.

Complete information on the ENERGY STAR® program, including the Green Lights Program, is available by calling the ENERGY STAR Hotline: (888) STAR-YES; www.epa.gov/energystar or www.energystar.gov.

The National Lighting Product Information Program (NLPPIP) of the Lighting Research Center at Rensselaer Polytechnic Institute offers independently evaluated product information, including manufacturer-specific test results on thousands of lamps, fixtures, ballasts, and controls; www.lrc.rpi.edu.

Exterior lighting improves security, enhances safety, and directs pedestrians and vehicles. It is also used in nighttime work areas, sports facilities, landscapes, and cityscapes. A wide selection of new lamps, ballasts, fixtures, and controls are available to lighting designers to replace inefficient exterior lighting systems. The use of white light sources increases nighttime visibility and maximizes peripheral vision. With any exterior lighting design it should be a high priority to avoid light pollution (the upward transmission of light) and light trespass (glare obnoxious to neighbors)—careful luminaire and lamp selection can minimize these problems.

Opportunities

Most exterior lighting systems using incandescent, mercury vapor, or sodium lamps should be evaluated, redesigned, and replaced with new hardware using compact fluorescent or metal halide lamps. In locations with nearby astronomical observatories, low-pressure sodium lighting may be appropriate, but otherwise both low-pressure and high-pressure sodium lighting should be avoided because the poor color rendering makes night vision very inefficient. Incandescent (halogen) exterior lighting may be appropriate when used with motion sensors where instant illumination is required and the total “on” time is low.

Exterior lighting systems that currently result in inappropriate glare, light trespass, and light pollution should be replaced. A parking lot that is lighted with floodlights, for example, can be relighted with IESNA full-cutoff luminaires and appropriate low-wattage lamps.

Technical Information

Exterior lighting principles should be considered when implementing any exterior lighting retrofit or new design. These principles assist in achieving energy conservation, provide superior lighting quality to users, and help preserve the night sky.

Minimize glare. Glare greatly detracts from nighttime visibility. If two parking lots are equally illuminated to 5 footcandles, the installation with the least glare from the fixtures will provide the greatest visibility, safety, and visual comfort. *Veiling luminance* is a numerical measure of glare and needs to be considered in roadway and parking area illumination calculations. *Light trespass potential* can also be evaluated.

Minimize or eliminate light directed upward. Light emitted at angles of 80° or higher (straight down is 0°) fails to produce useful illumination on horizontal surfaces in open areas such as parking lots. At these high angles light produces significant glare, light pollution, and wasted energy. Light above 90° (horizontal) is totally wasted and produces undesirable sky glow.

Direct light only where it is needed. New fixtures allow designers to control where light falls. By eliminating light spillage into surrounding areas, lower wattage lamps can be used. “Barn lights” that contain 175-watt mercury vapor lamps, wall packs, and floodlights are good examples of fixtures to avoid.

Avoid overlighting. Refer to the *IESNA Lighting Handbook – 9th Edition* (2000) for lighting quality and quantity guidelines. Minimum levels are required for different uses, with maximum to minimum uniformity requirements. Lighting quality is directly related to good uniformity, not to the number of footcandles. A good rule of thumb is that “a little light is a lot of light where there isn’t any other light.”

Consider human usage patterns. Where pedestrians are likely along roadways, for example, provide high-quality (white) vertical light that allows plenty of time for both pedestrians and motorists to be seen.

LAMP AND BALLAST SELECTION

Mercury vapor lights should be avoided. Replace mercury vapor lights with metal halide lights whenever possible.

Low-pressure sodium lamps provide the highest efficacy (lumens per watt) of any light source, but this light source is appropriate only in rare situations. The monochromatic yellow light they produce has absolutely no color rendering capability. Three cars—red, blue, and black—may all appear identical under these lights. In fact, despite the high efficacy, low-pressure sodium is actually among the least efficient nighttime light sources in terms of providing visibility. However, if astronomical observatories are nearby, low-pressure sodium may be a desirable exterior lighting option because filters for specific wavelengths can be installed on telescopes.

High-pressure sodium lights, though they provide significantly better light quality than low-pressure sodium, do not provide nearly as good nighttime illumination as metal halide (a much whiter light). They do offer long life, however. Many high-pressure sodium ballasts with igniters can accept metal halide lamp retrofits.



Source: Kim Lighting

Full-cutoff luminaires direct nearly all of their light downward, thus reducing light pollution.

Metal halide is generally the best option when very high levels of illumination are required. The efficacy is good and the light is very white.

Inductive lamps provide high-quality white light and are an increasingly attractive exterior lighting option.

Compact fluorescent exterior lighting is appropriate for many applications, especially along walls and in low outdoor fixtures.

Some high-intensity discharge (HID) ballasts incorporate control circuits that allow easy attachment of motion sensors or energy management system controls. To maximize lamp life, specify ballasts that provide the least amount of voltage variation to the lamps.

Use HID lamps with specific orientations rather than universal position lamps. Lamps that specify burning in the horizontal, base-up, or base-down positions can produce 10–20% more light and last up to 60% longer.

Consider photovoltaic lighting for remote sites not yet served by power lines. Locations requiring low levels of light that are further than 50 feet (15 m) from a power source can be good applications for PV lighting. Examples are signs and bus shelter lights (See Section 5.8.5 – *Photovoltaics*).

CONTROL AND MAINTENANCE

Turn off lights by 11:00 p.m. unless they are needed for security or safety. In little-used parking areas, illumination may not be needed that late. Consider motion sensors when only brief periods of illumination are needed.

Control of exterior lighting may be provided by manual switches, time clocks, photocells, motion sensors, or sophisticated energy management systems. FM-frequency and satellite controls are available for very large installations. By automating controls, users need not manually switch lights on and off each night. Where time clocks are used, however, they should be periodically checked to ensure that the time is set correctly and adjusted for changes in time of sunrise and sunset. Where photocells are used, they should be very sensitive to low light levels and placed in open areas, such as on roofs. This will help to ensure that lights do not operate unnecessarily at dusk and dawn. See Section 5.4.4 – *Lighting Controls* for more information about control systems.

Design systems to provide for cost-effective maintenance. To reduce maintenance costs, provide long ballast and lamp lives, and provide equipment that is resistant to dirt, animal droppings, birds' nests, vandalism, and water damage.

Relamp groups of fixtures at the same time to reduce maintenance costs, lamp stocking, and light depreciation toward the end of lamp life.

References

IESNA Lighting Handbook – 9th Edition, Illuminating Engineering Society of North America, New York, NY, 2000; (212) 248-5000; www.iesna.org.

Leslie, Russell, and Paula Rodgers, *The Outdoor Lighting Pattern Book*, McGraw-Hill, New York, NY, 1996.

Lighting for Exterior Environments (RP-33-99), Recommended Practice Series, Illuminating Engineering Society of North America, New York, NY, 1999.

Contacts

International Dark-Sky Association, 3545 N. Stewart Avenue, Tucson, AZ 85716; www.darksky.org/; offers information on techniques for providing good outdoor lighting without contributing unnecessarily to light pollution.

Office, Food Service, and Laundry Equipment

Some of the many different energy-consuming devices in Federal buildings are only recently beginning to receive attention relative to their power and water consumption. Office equipment, food service equipment, and laundry equipment provide excellent opportunities for reducing energy consumption. Indeed, office equipment represents the fastest growing use of electrical energy in U.S. commercial buildings. These products are discussed in general here and in more detail in the following two sections.

Opportunities

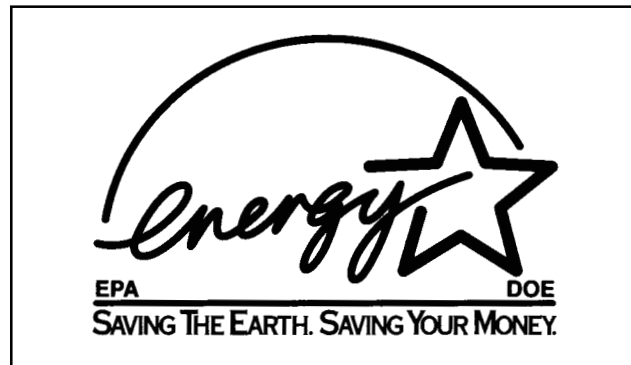
When selecting office, food service, or laundry equipment, the facility manager may reduce energy consumption by opting for the high-efficiency, high-performance equipment described in *Section 5.5.1* and *Section 5.5.2*.

Technical Information

Selecting energy-efficient office equipment—personal computers (PCs), monitors, copiers, printers, and fax machines—and turning off machines when not in use can result in enormous energy savings. A typical

PC operating 9 hours a day will use only 38% of the power consumed by a computer operating 24 hours. Power management devices on computers can reduce energy usage even further by turning down the power when the computer is not being used. Copiers, laser printers, faxes, and other office equipment can save up to 66% of their 24-hour power consumption by keeping them on only during office hours.

EPA's ENERGY STAR® program, which began in 1992, was reinforced by a 1993 Executive Order requiring all Federal agencies to purchase only ENERGY STAR-compliant computers. Office equipment qualifying for this program must have the capability of powering down to a low-power mode after a user-designated period of inactivity.



High-capacity, multistage dishwashing machines are designed for medium-to-large food service operations, including hospitals, colleges, prisons, hotels, and restaurants. Multistage dishwashers reuse water from the two rinse stages to prewash the dishes. In addition to the water savings, these devices save considerable amounts of detergent and rinse additives. Because of the improved design of the dishwashers, dish breakage has been reduced.



Source: Jackson MSC, Inc.

This commercial dishwasher handles up to 57 racks per hour with a 58-second wash/rinse cycle. It uses only 1 gallon (3.8 liters) of water per rack, less than the amount required by competitive machines. In addition to savings on water and sewer charges, a built-in booster heater cost-effectively raises incoming water temperature to commercial standards—typically 180°F (82°C).

Before upgrading a kitchen, consider the following energy-efficient types of equipment: infrared fryers, convection ovens (including steamer models), microwave ovens, and specialized equipment such as pizza ovens. Computerized controls can produce savings because they automatically time the cooking of certain foods. Energy-efficient exhaust hoods can provide significant savings because they use outside air rather than indoor conditioned air for ventilation. Side curtains around cooking equipment help restrict the flow of conditioned air to the outdoors. Exhaust air can be used to preheat air for HVAC purposes or to preheat water (see *Section 5.3.1 – Heat-Recovery Water Heating*).

Microcomputers on newer-model clothes washing machines permit precise control of water temperature and cycles. Horizontal-axis and other high-efficiency ENERGY STAR clothes washers use significantly less water and energy than conventional vertical-axis machines. Operate washers and dryers with full loads rather than partial loads in order to save energy.

Laundry water temperatures should be reduced to 160°F (71°C) unless prohibited by codes. Some soaps and detergents will perform at even lower temperatures, and their use is encouraged. Water temperatures should be checked with an accurate thermometer, and the equipment settings should be adjusted as needed.

Contacts

Complete information on the ENERGY STAR program is available by calling the ENERGY STAR Hotline at (888) STAR-YES or through the ENERGY STAR Web site at www.epa.gov/energystar or www.energystar.gov.

5.5.1 Office Equipment

Office equipment is the fastest-growing use of electricity in commercial buildings in the United States, accounting for 7% of all commercial-sector power consumption. We spend \$1.8 billion each year to operate office equipment in businesses and homes. ENERGY STAR® office equipment is widely available that provides users with dramatic savings compared with non-ENERGY STAR equipment—as much as 90% savings in some product areas. More than 3,300 office products are ENERGY STAR-labeled. Along with saving energy directly, this equipment can reduce air-conditioning loads, noise from fans and transformers, and electromagnetic field emissions from monitors.

Opportunities

When new office equipment is purchased, be certain that the products are ENERGY STAR-compliant, as required by Executive Order 12845 (signed April 1993). Also, provide education about the use of office equipment for optimal energy efficiency as part of new-employee training, and send periodic reminders to employees—through e-mail or print newsletters and other in-house communication vehicles—about the use of equipment.

Technical Information

COMPUTERS

To save energy used by computers and monitors, buy ENERGY STAR-listed equipment or consider laptop computers. ENERGY STAR computers must have a power-saving mode that powers down to no more than 15% of maximum power usage. ENERGY STAR monitors power down to 15 watts or less after 15–30 minutes of inactivity, and then down to 8 watts or less after about 70 minutes of inactivity.

Laptop computers save even more energy than ENERGY STAR-rated desktop computers/monitors. Laptops draw only 15–25 watts during use, compared to the 150 watts used by a conventional PC and monitor, and their sleep mode typically uses just a fraction of a watt. To maximize savings with a laptop, put the AC adapter on a power strip that can be turned off (or will turn off automatically)—the transformer in the AC adapter draws power continuously, even when the laptop is not plugged into the adapter.

ENERGY STAR computers and monitors save energy only when the energy management features are activated. ENERGY STAR products are shipped with energy-saving features activated. Employees should be able to adjust the energy-saving features to suit their particular needs and work habits (e.g., the length of time before power-down), but discouraged from deactivating those features.



Obtaining maximum energy savings from computers that are on networks can be difficult. There are many combinations of hardware, operating systems, applications software, and peripherals that may affect the sleep mode of computers. The “failure mode” for ENERGY STAR personal computers is for the computer to stay awake, or the network management staff may simply deactivate the power management system on the computer. In contemplating large purchases of PCs, first purchase a single machine to find out whether the power management works as designed with the network and software that will be used.

The monitors must be capable of entering a low-power state. Monitors must be capable of being shut off by a Display Power Monitoring Signal (DPMS) signaling protocol, by a software utility, or by a special plug connected to the PC. “Universal” monitors can both accept a DPMS from a PC and run power management from a non-DPMS PC.

Screen savers do not save energy. There is a common misconception that screen savers reduce energy use by monitors—they do not. Automatic switching to sleep mode or manually turning monitors off is always the better energy-saving strategy.

Turn computers and monitors off at night, on weekends, and during the day when they are not in use. Turning computers off saves more electricity than having them in sleep mode. A 150-watt PC and monitor will cost about \$105 per year to operate if left on continually. Turning it off at night and on weekends will save about \$80 per year in energy costs. Turning it off when not in use during the day can save another \$15 per year.



ENERGY STAR-qualified office equipment switches to low-power modes after short periods of inactivity, thereby realizing significant energy savings compared with non-ENERGY STAR models.

Photos: www.officecopier.com

PRINTERS/FACSIMILE MACHINES

ENERGY STAR printers and fax machines power down to a maximum of 15–45 watts, depending on the output speed (pages per minute), after a predetermined period of inactivity. Ink-jet and bubble-jet printers use significantly less electricity than laser models.

Use a network or printer-sharing switch rather than buying one printer per worker.

Reduce printer use by implementing paper reduction strategies, using duplex printing features (two-sided printing), and encouraging the use of e-mail.

Consider new printers. Although older ENERGY STAR printers required a delay time to return to print mode, newer models return to operating mode almost immediately from low-power mode.

Use plain-paper fax machines to save money. Thermal fax paper is not acceptable in typical paper recycling programs. For higher-usage offices, avoid fax machines that generate substantial waste by using a film cartridge.

Use e-mail or direct computer faxing instead of paper faxes whenever possible.

COPIERS

ENERGY STAR copiers must power down to a low-power mode after 15 minutes of inactivity and an “off-mode” of lower power use (5–20 watts) after no more than 120 minutes of inactivity. Specific ENERGY STAR standards depend on the copier speed (copies per minute). The smallest copiers (less than 20 copies per minute) do not have the intermediate low-power mode and are preset to power down to an “off mode” of no more than 5 watts after 30 minutes of inactivity.

Copiers use more energy than any other piece of office equipment. Be sure to buy an ENERGY STAR copier that is sized correctly for the job.

Purchase correctly sized copiers. A mid-volume copier installed in a low-volume office can use 70% more energy per page than an efficient low-volume copier!

Use e-mail, Web sites, and “paperless faxing” when possible.

Select double-sided copying, an important energy- and paper-saving feature. Set copiers to automatically default to duplex copying.

Purchase paper with a high recycled content. At a minimum, use paper meeting the required recycled content for Federal purchasing—if possible, use higher-recycled-content paper.

Copy in batches. Significant reduction in energy consumption can be achieved by scheduling copier projects in batches so that the printer spends far less time in high-power mode.

References

Tiller, D. K., and G. R. Newsham, “Switch Off Your Office Equipment and Save Money,” *IEEE Industry Applications Magazine*, 2(4), 1996, pp. 17–24.

Contacts

Complete information on the ENERGY STAR program is available by calling the ENERGY STAR hotline at (888) STAR-YES or through the ENERGY STAR Web site at www.epa.gov/energystar or www.energystar.gov.

Lawrence Berkeley National Laboratory’s Web site includes a list of resources on reducing office equipment energy use: eetd.LBL.gov/BEA/SF/.

Food service and laundry equipment can be some of the heaviest consumers of energy and water. New types of high-capacity, multistage dishwashing machines, high-efficiency refrigerators, advanced cooking equipment, and new clothes washers provide significant opportunities to save resources and money. In each case, heat recovery systems can be used to capture waste energy from appliances and use it to preheat air for HVAC purposes or to preheat water.

Opportunities

Make energy efficiency and water efficiency key considerations when outfitting a new kitchen or laundry for a Federal facility, as well as when renovating these spaces or replacing individual pieces of equipment. In certain situations, replacement will be justified solely on the basis of energy savings. Also consider measures to recover waste heat at the time of new equipment selection or kitchen/laundry renovation.

Technical Information

DISHWASHERS

New high-capacity, multistage dishwashing machines are designed for medium-to-large food service operations, including hospitals, colleges, hotels, and restaurants. In addition to reducing water usage and load requirements, labor requirements for operation are reduced by 50%.

Multistage dishwashers reuse water from the two rinse stages to prewash dishes. In addition to reducing water consumption, these devices save a considerable amount of detergent and rinse additives. Because of their improved design, breakage is also significantly reduced.

Power scrapers are available for some dishwasher models that remove caked-on, dried food. This can be particularly useful when there is a significant time lag between use and washing.

Typical throughput of dishes in a high-capacity, multistage washing machine is 3,500 to 3,700 dishes per hour, with a conveyor speed of 5 to 6 feet (1.5 to 1.8 m) per minute.

A recent Department of Defense cafeteria installation of the new multistage dishwashing equipment cost \$57,800. The result was a water reduction of 500,000 gallons (1,900 m³) per year, saving \$2,000 per year. Labor savings were \$19,000 per year. The payback time for this installation was 2.7 years, and it will save almost \$500,000 over its 25-year projected life.

REFRIGERATORS AND FREEZERS

In commissaries, refrigerators and freezers can account for up to 50% of energy consumption. Energy efficiency advances in commercial refrigeration have paralleled those in residential refrigeration since the 1970s.

Refrigerators and freezers are divided into medium-temperature (MT) systems—down to 20°F (-7°C)—and low-temperature (LT) systems—down to -25°F (-32°C).

New equipment is available with EERs of 7 to 9 for MT systems and 5 to 6 for LT systems. Replace old, inefficient systems with high-efficiency, new systems to obtain significant savings immediately.

Relying on refrigerator cases to cool the interior of a space is not very useful, as HVAC systems typically have EERs of 10 to 12 versus the 5 to 9 for refrigeration equipment. This translates to a difference of 40% in energy use. Air spillage from the refrigeration equipment should be minimized.

Product literature specifies proper operation and maintenance of refrigerators and freezers. Some of the causes of excessive energy use by these devices are controls set too low, doors that do not close properly, and worn or torn gaskets. An accurate thermometer is needed to check temperature conditions. Cleaning condenser heat transfer surfaces to remove dirt and scale is very important for proper and efficient operation. Overloading the unit may result in over- or undercooling the stored food.

COOKING EQUIPMENT

The key strategies for saving energy when using cooking equipment are (1) turn equipment off when not in use, (2) use a temperature no higher than necessary, (3) match the equipment to the job, and (4) cook as efficiently as possible. The last step includes adjusting flames on ranges to just touch the bottom of cookware, avoiding unnecessary oven door openings, cooking foods with the same requirements simultaneously, and cooking in volume.

When upgrading a kitchen, consider the following energy-efficient types of equipment: infrared fryers, convection ovens (including steamer models), microwave ovens, and specialized equipment. Specialized equipment (such as a pizza oven) is designed to cook specific foods very efficiently. Computerized controls can also produce savings by automatically timing the cooking of certain foods.

Energy-efficient exhaust hoods can provide significant savings because they use outside air rather than inside conditioned air for ventilation. Side curtains



Source: Bruce Wagman Photography/Maytag

Maytag's commercial H-axis Neptune washer uses significantly less water and energy than top-loading models.

around cooking equipment can help restrict the flow of conditioned air to the outside. Exhaust air also can be used to preheat air for HVAC purposes or to preheat water.

LAUNDRY EQUIPMENT

Horizontal-axis (H-axis) washing machines are far more energy- and water-efficient than conventional top-loading, vertical-axis machines. American manufacturers have only recently begun to reintroduce H-axis equipment for residential use. H-axis commercial equipment has been available for many years, but new products (based on residential models) have been introduced recently. One manufacturer has designed a resource-efficient vertical-axis residential washer that performs far better than typical top-loaders and meets ENERGY STAR® standards. Look for washing machines that meet ENERGY STAR requirements for water and energy savings.

Laundry water temperatures should be reduced to

160°F (71°C) unless prohibited by code. Some soaps and detergents perform well at lower temperatures and should be used where appropriate. Temperatures should be checked with an accurate thermometer, and equipment should be adjusted as needed.

Microcomputers on newer-model laundry equipment permit the precise control of water temperature, wash cycles, and drying.

Large commercial laundries should consider water recycling and batch tunnel washers as water-conservation measures. Continuous-batch machines conserve water and energy, as do machines that recycle the final rinse for use as the first wash on the next batch.

Using equipment efficiently means ensuring that washing machines and dryers are operated with full loads rather than partial loads.

To reduce energy use by clothes washers and dishwashers: repair leaks, insulate storage tanks and distribution piping, clean sediment out of equipment, and test/tune-up water-heating components.

OTHER KITCHEN AND LAUNDRY IMPROVEMENTS

Add drainline heat-recovery equipment where practical. These units can capture a significant portion of the heat from hot water going down the drain (see Section 5.3.1 – Heat-Recovery Water Heating).

Replace conventional garbage disposals with pulpers. These recirculate a portion of the water instead of washing it all down the drain. Some systems allow ground-up materials to be composted instead of disposed of in the sewer system.

Provide foot controls on sinks. These permit easy control of sinks and can save tremendous quantities of water in situations where water is commonly left running throughout a specific task. Water can be turned on and off without changing the temperature mix.

Install low-flow faucet tops for sinks that provide adequate waterflow but no more than needed (see Section 6.3 – Showers, Faucets, and Drinking Fountains). Aerating devices should be avoided, particularly in health facilities, because the screens can harbor germs and pathogens. Flow restrictors should be avoided.

References

The Most Energy-Efficient Appliances – 1999 Edition, American Council for an Energy-Efficient Economy (ACEEE), Washington, DC; www.aceee.org.

Appropriate control systems allow facility managers to automate functions that would be impossible or impractical to control manually. Automatic controls are useful with lighting, air distribution systems, chillers, boilers, heat pumps, pumping systems, compressed air systems, water heating, and other major energy-consuming equipment. Controls may be simple and inexpensive, or complex and costly. Simple controls, including time clocks, occupancy sensors, photocells, and programmable thermostats, are discussed in this section. More sophisticated, computer-based energy management and control systems (EMCSs) that monitor hundreds or thousands of “points” throughout a facility are discussed in *Section 5.6.1*. Some control systems designed to reduce peak electrical demand and lower utility bills are covered in *Section 5.6.2 – Managing Utility Costs*. Most of the discussion on lighting controls is found in *Section 5.4.4*.



Power outages disrupt schedules of electromechanical time clocks because the time setting is lost; battery backup may be justified in locations with frequent loss of power. Daylight Savings Time shifts also require resetting of clocks.

Opportunities

Facility managers should consider automatic controls and sensing technology when equipment can be turned on, shut off, or modulated based on schedules, temperatures, pressures, light levels, or the presence or absence of personnel. HVAC and lighting are prime candidates for automatic controls. It is easiest to add (or change) control systems when the HVAC or lighting systems are being replaced or modified in other ways, though controls can often be retrofit fairly easily.

Technical Information

The following is general information about some of the common controls available to help reduce energy consumption.

Time clocks are electrical or electromechanical devices that can turn equipment on and off according to a schedule. Small loads can be switched directly, and large loads can be controlled indirectly through the use of relays. Many time clocks are 24-hour devices that repeat programs every day. Some have weekly and even annual wheels that allow more complex programming patterns. Although it will minimize wiring costs, locating time clocks near the circuits they control is not necessary. Maintenance staff must have easy access to controls to carry out preventive maintenance and to ensure that the control equipment is operating properly.

Occupancy sensors detect whether people are present by sensing heat (infrared), motion (ultrasonic), or sound. Some systems directly control small lighting loads at line voltage and directly replace wall switches.



Standard time clocks usually do a poor job of controlling exterior lights because they do not account for daily changes in sunset and sunrise.

Others are part of more complex systems that may include several sensors, control logic, and an interface to the load. Facilities that have EMCSs may also make use of occupancy sensors to control lights and certain HVAC operations.

Programmable electronic thermostats allow facility managers to reset heating and cooling setpoints for different operating modes. Daytime, nighttime, and weekends typically have different target temperatures in order to allow the building temperature to drift appropriately when unoccupied, then return automatically to occupied mode.

Timers are simple devices that automatically turn off loads after a predetermined number of minutes or hours. They can be used to control bathroom exhaust fans, for example, allowing moisture removal for a predetermined period of time after showering—thus eliminating the need for continuous operation. Timers are sometimes more cost-effective than occupancy sensors in controlling lighting and fan loads in areas that are used infrequently. These can either be mechanical, with spring-wound mechanisms, or electronic, with digital controls. The latter are quieter and can be programmed for different time-out periods.

Photocells are devices that open and close switches in response to light levels. Some photocells are not very sensitive to low light levels at dusk and dawn and may, for example, switch outdoor lights on in the evening before light is needed. This wastes energy and, in some cases, can increase demand charges. Photocells are also used to dim fluorescent lights inside buildings where electric light levels are regulated on the basis of available daylighting (see *Section 5.4.4 – Lighting Controls*).



To avoid injury, it is important to post signs indicating the control mechanism and to install disconnect switches near equipment operated by automatic controls.

When purchasing programmable thermostats made for use with heat pumps, ensure that they have “ramped recovery” features for heating. Ramped recovery slowly brings the building up to the target temperature without engaging the supplementary electric strip heating.

Facility managers should document all the automatic controls in their facilities by recording the locations of controls, the equipment being controlled, and any requirements for resetting the time or program as seasons change, as time changes for Daylight Savings, or after power outages.

Electrically combining time clocks and photocells may provide a good way to program the needed exterior lighting logic—for example, “on at sunset, off at 10:00 p.m.” Facilities with EMCS equipment should have no trouble implementing this type of control logic.



Sophisticated electronic controls, such as programmable thermostats and EMCSs, can be prone to problems with electrical power quality: surges, spikes, brownouts, and outages, particularly in locations distant from utility substations. Putting this equipment on circuits with surge suppression or uninterruptible power supply (UPS) may be advisable.

Energy Management and Control Systems

An energy management and control system, or EMCS, reduces energy use in buildings by monitoring conditions and controlling energy-consuming equipment. An EMCS is typically applied to the largest electrical loads, including HVAC equipment, cooling towers, pumps, water heaters, and lighting. Control functions may include everything from basic stop/start functions to more complex chiller optimization routines. An EMCS can be used in new or existing facilities and can interface with existing controls, such as pneumatic damper actuators. EMCSs typically save money in two ways: by reducing energy use and by reducing labor costs. EMCSs can have very favorable paybacks, especially where existing control systems are lacking or have problems. By tracking system operation using an EMCS, a facility manager can perform diagnostics and optimize system performance.

Opportunities

Facility managers should consider installing an EMCS in any facility expansion. EMCS retrofits are often justified and can involve improving chiller or boiler controls, adding economizer cycles, controlling lighting loads, and limiting electrical demand. An EMCS can be particularly reliable for very large or widely dispersed facilities. Be sure to consider adding an EMCS when modifications to HVAC and lighting systems are being considered for other reasons—such as the downsizing of mechanicals to pay for cooling-load-reduction measures. Strategies for load management are covered in *Section 5.6.2 – Managing Utility Costs*.

Technical Information

An EMCS can perform various functions, from simple single-point control to multifunction systems with complex decision logic. Fully functional EMCSs provide the greatest potential for maximum energy and cost savings.

Hardware varies in complexity. Simple systems include actuators that switch or change loads according to signals from local controllers that contain control logic. More sophisticated systems add sensors or monitoring points, field termination panels for minimizing control wiring, modems, communication links, and central computers. Software often includes

sophisticated user interfaces that graphically depict equipment, sensors, and controls.

Distributed or networked systems combine the reliability of local controllers with the advantages of facility-wide monitoring. Centralized control provides facility engineers an immediate interface with remote equipment, allowing quick diagnosis of problems and quick response to complaints.

FUNCTIONAL CAPABILITIES

Many scheduling, optimizing, and reporting functions are available with an EMCS:

Start/stop controls will limit operating hours of equipment according to predetermined schedules.

Optimum start/stop controls delay bringing equipment online until the latest possible time. This is particularly useful in limiting HVAC operation.

Temperature setback/setup saves energy by allowing building conditions to drift (within predefined limits) during unoccupied periods.

Economizer controls turn off chillers during mild weather and allow outside air to provide space conditioning.

Enthalpy control provides more sophisticated economizer control that is based on both temperature and humidity.



HELPFUL TIPS

- Train key employees to use the EMCS once it is installed.
- Have a qualified engineering firm design specifications before bidding any EMCS.
- Require the vendor to fully demonstrate the system and all software before delivery. Videotape the demonstration and training for use during refresher training.
- Design expansions of EMCSs to have a single-user interface system in order to avoid operator confusion.



A sophisticated energy management and control system is helping the Rockland County Community College in New York realize substantial energy savings. Dual-fuel boiler controls allow the college to switch between oil and gas, depending on current market conditions. Source: NYSERDA

Supply temperature reset modulates circulating water temperature based on load sensors and program logic.

Boiler optimization balances fuel and combustion air according to actual heating loads.

Duty cycling can help reduce utility peak demand charges by turning off equipment for a predetermined percentage of time.

Demand limiters shed nonessential equipment, such as water heaters, to reduce peak power demand to a preset level.

Alarm functions alert operators to conditions outside preestablished ranges.

Monitoring provides the capability to track (1) equipment run-time and other parameters for proactive maintenance, and (2) energy consumption for cost containment.

Load management controls stage the start-up of large equipment to avoid power peaks.

OPERATION AND MAINTENANCE

Use in-house staff for day-to-day service requirements, provided that they have adequate skills and are well trained. Service contracts can be very expensive and should be used only when necessary.

Sensors should be checked and calibrated on a regular maintenance schedule. Failed sensors and false readings can waste a considerable amount of energy.



CAUTIONARY NOTES

- New EMCS systems will not necessarily interface properly with existing controllers and other components that are intended to remain in place.
- Be careful about buying “custom-built” systems. Purchase proven systems and software that has a good track record. Request systems with open protocols to improve compatibility with future systems.
- Sole reliance on the EMCS console can lead to misdiagnosis. For example, a temperature alarm would prompt the operator to check the position of the VAV damper for that zone. If the sensor indicated that the damper was fully open and yet the zone was too hot, the operator might reset the chilled water temperature. However, the combination of a stuck damper (cutting off airflow) and a loose damper shaft (allowing the control system to believe the damper is operating normally) might be the real problem. This situation could easily fool both the control system and the operator.

References

“Energy Management Systems” (Technical Brief TB.EMU.121.4.87), Electric Power Research Institute, 3412 Hillview Avenue, Palo Alto, CA 94304; (650) 855-2000; www.epri.com. The EPRI Web site lists summaries of a large number of technical reports available on various aspects of energy management.

Utility bills for large facilities include demand charges that can amount to one-third of monthly electricity costs. Demand, measured in kilowatts, is the average electrical load over a small period of time, usually 15 or 30 minutes. Facilities are billed for the largest peak demand during the billing period. Electrical demand peaks can be lowered in several ways: shedding unneeded loads, rescheduling loads, staging equipment start-up, generating power on-site, or switching to another fuel. Keep in mind that there will be a lot of changes in the coming years as a result of utility deregulation (restructuring). In restructured power markets, some innovative market-based utility partnerships are emerging with large power users. At the same time, however, volatile energy prices are likely to be reflected in price increases to customers.

Opportunities

Facilities with low load factors or steep load-duration curves are the best candidates for cost-effective peak shedding. Facilities using energy management and control systems may already have most of the hardware and software needed to institute a load-shedding program. As utility restructuring becomes more common, look into innovative load-shedding arrangements with utility companies—e.g., apportioning some load as interruptible and selling to the utility company the right to shed that load during peak-demand periods; such arrangements can be very attractive financially.

Technical Information

Utility tariffs usually encourage demand control and load shifting. Facility managers should understand how their facilities are charged for power and energy (be aware that with utility restructuring, there are likely to be significant changes in the coming years). Here are three utility pricing elements common today:

- **Demand charges** are based on the highest monthly power peak, measured in kilowatts (kW). All but the smallest facilities will be billed for demand. This charge reflects the electric utility's infrastructure cost of power generation and transmission and the more expensive fuels used in peaking plants. Summer-peaking utilities tend to have higher summer demand charges, and winter-peaking utilities (increasingly rare) have higher demand charges during winter months.
- **“Demand ratchets”** are minimum demand bills based on some percentage of the highest peak power metered over the preceding year. Thus, one month's high demand can affect monthly charges for an entire year.
- **Time-of-Use (TOU) tariffs** offer discounted rates for power used at times the utility establishes as off-peak. The difference in energy charges (per kWh) between on-peak and off-peak power can be a factor of two to four.

DEMAND SHEDDING

Demand-shedding or peak-shaving strategies include purchasing smaller, more efficient equipment; altering the on-times of existing equipment; switching fuels during peak periods; and generating power on site. Some popular strategies are as follows:

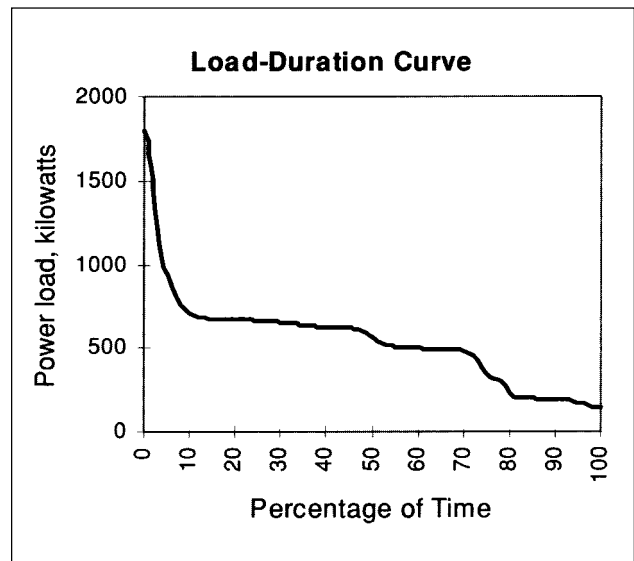
- **Duty-cycling** strategies attempt to limit the operation of equipment to certain times within a utility's demand period. Duty cycling has limited application because of stresses on frequently cycled equipment and the effect on the building or its systems. For instance, duty cycling of cooling tower motors would allow the chilled water temperature to rise. Cycling a ventilation fan might compromise indoor air quality or adversely affect building pressures.
- **Demand limiters** shed loads in a preestablished order when demand targets are about to be exceeded. Two main algorithms are used: simple and predictive (or slope-sensitive). Simple demand limiters can result in undesirably high load-shedding frequencies and cannot control demand closely.
- **Generators** can be used to keep equipment operating while off-grid. If the same generators provide emergency backup power, precautions must be taken to ensure that emergency power is available even during peak periods. If critical loads also contribute to facility peaks, consider shifting these loads to generator power during peak periods.
- **Dual-fuel heating and cooling** equipment can provide a nonelectric means of meeting space-conditioning requirements during times when using electricity would be expensive. For example, hybrid cooling systems, fueled by either natural gas or electricity, can dramatically lower electricity demand by using natural gas at peak hours.

- **Battery storage** generally is not cost-effective for peak reduction unless batteries are in place for other purposes. One situation where battery storage may make sense is for off-peak charging of forklifts that are used during daylight hours.
- **Thermal storage** involves storing thermal capacity generated off-peak for on-peak use. During the peak periods of the day, circulating water is cooled by ice baths or chilled water tanks (instead of chillers) to provide space or process cooling. Precooling a building at night before a predicted hot day so that chillers will not have to work as hard is another form of thermal storage. Water storage is not as common as ice storage because of the extra volumes needed to store thermal energy without phase changes.
- **Dispatchable load shedding** is a direct load-control technique in which the utility controls the times that a customer's equipment is shed under a prearranged agreement. Such arrangements can benefit both parties and justify on-site generation or alternative fuels. In some cases, the utility company may sell that additional power, taking advantage of price spikes in wholesale power markets and sharing a portion of the windfall profits with the facility. With utility restructuring, look for innovative market-based load management arrangements such as this.
- **Cogeneration** of electricity and steam from gas turbines and other power-generation technologies may be cost-effective for large facilities.

Facilities with steep load-duration curves are well suited for applications of peak-shaving technologies. Load-duration curves, such as the one shown in this section, are generated by sorting electrical loads recorded for each hour of the year. Data may be available from the electrical utility or from the facility's energy management system.

Track load factors each month to check utility demand charges. The formula for calculating the load factor is shown below. Load factors greater than 100% are impossible and indicate metering or billing problems. Load factors that suddenly deviate from historical

$$\text{Load Factor} = \frac{\text{Monthly kWh}}{\text{Monthly peak kW} \times 24 \times \text{No. of days in billing period}}$$



High loads, occurring only a small percentage of the time, can lead to very high demand charges.

values also indicate problems. If problems are found, recheck the billing information and contact the utility.

If the facility has a high minimum-demand billing, find out if the utility has a “ratchet release” provision to reset the minimum demand to a lower level based on measures implemented by the facility.

With the use of daylight-linked dimmable lighting ballasts, both lighting and subsequent chiller loads can be reduced. Allowing temperature and humidity to drift slightly is another effective strategy. According to ASHRAE, one-hour excursions out of the standard comfort envelope will be unnoticeable to most building occupants.

Contacts

Electric Power Research Institute, 3412 Hillview Avenue, Palo Alto, CA 94304; (650) 855-2000; www.epri.com.

Electric motors vary greatly in performance. The selection of energy-efficient motors for HVAC equipment and other applications in existing or new facilities can greatly reduce energy consumption. Recent developments in energy-efficient motors and motor controls allow facility managers to significantly reduce energy consumption in some Federal facilities.

Opportunities

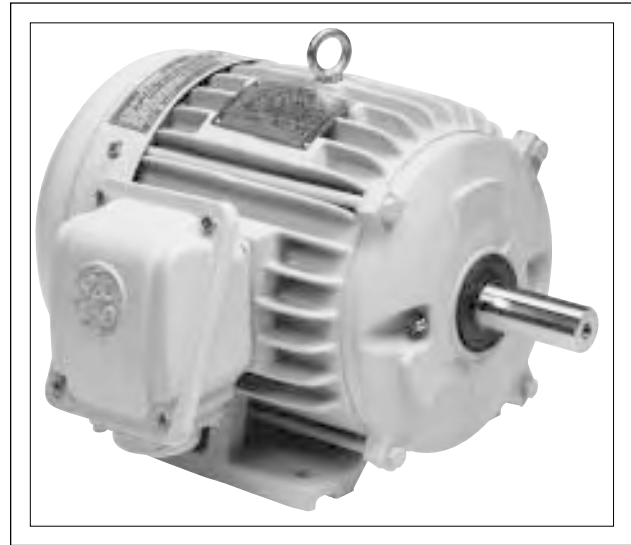
For new facilities, high-efficiency motors should be specified during design. In existing facilities, facility managers should inventory all motors, beginning with the largest and those with the longest run-times. This inventory permits informed decision-making about replacement, either before or after motor failure. Field-testing of motors enables the facility manager to properly size replacements to match the actual driven load. The software mentioned in this section can help with this inventory.

Technical Information

The Motor Challenge Program was developed by DOE to assist industrial customers in increasing their use of energy-efficient motor systems. Federal facility managers can also benefit from Motor Challenge through a special arrangement with FEMP, receiving technical assistance, training, software, and other materials.

MotorMaster+ is a PC-based software tool that helps the user to inventory and select motors. A database of 12,000 new motors contained in the software includes horsepower, speed, enclosure type, manufacturer, model name, catalog number, voltage, nominal efficiencies at various loads, torque and current characteristics, power factor, warranty, and list price. The software allows users to simulate replacement scenarios to determine the lowest life-cycle cost options for existing motors.

The inventory features in **MotorMaster+** help facility managers track motors, including their location, and electrical measurements needed to determine loading. Developing an inventory is the first step in establishing a motor rewind/replacement policy that could



This high-efficiency motor is designed to work with a variable-frequency drive.

Photo: General Electric

significantly reduce operating expenses. Since motors are typically replaced or rewound when the motor fails, having an inventory will allow facility managers to quickly determine the most economical approach to take and assist in proper equipment selection. Inventoried motors also can be evaluated to set priorities for the replacement of functioning motors with premium-efficiency motors.

Turn off unneeded motors. Identify motors that operate unnecessarily, even for a portion of the time they are on. For example, waste may occur with multiple HVAC circulation pumps operating even when demand falls, cooling-tower fans operating when target temperatures are met, ceiling fans operating in unoccupied spaces, exhaust fans operating after ventilation needs are met, and escalators operating after closing time. In all these cases, simply turning off the motors can produce significant energy savings.

Reduce motor system usage. Building design, maintenance, and operation can greatly affect the run-time of motors. For example, reducing cooling loads in a building will reduce the amount of time air handler motors need to operate. The following is a list of strategies for reducing the use of motors.



REDUCE MOTOR SYSTEM USAGE

- **Reduce loads on HVAC systems:**
 - Improve building shell energy performance.
 - Improve HVAC performance.
 - Check refrigerant charge.
- **Reduce refrigeration loads:**
 - Improve insulation.
 - Add strip curtains on doors.
 - Calibrate control setpoints.
 - Check refrigerant charge.
- **Check ventilation systems for excessive air:**
 - Reseal fan if air is excessive.
 - Downsize motors if possible.
- **Improve compressed-air systems:**
 - Locate and repair compressed-air leaks.
 - Check air-tool fittings for physical damage.
 - Turn off air to tools when not in use.
- **Repair duct leaks.**

Sizing motors is important. Do not assume that an existing motor is properly sized for its load, especially when replacing it. Many motors operate most efficiently at 75–85% of full-load rating. Undersizing or oversizing reduces efficiency. For large motors, facility managers may want to seek engineering help in determining the proper sizes and actual loadings of existing motors. There are several ways to estimate actual motor loading: the kilowatt technique, the amperage ratio technique, and the less-reliable slip technique. All three are supported in the *MotorMaster+* software.

Instead of rewinding small motors, consider replacing them with energy-efficient models. For larger motors, if rewinding offers the lowest life-cycle cost, select a rewind facility with high quality standards to ensure that motor efficiency is not adversely affected. For sizes of 10 hp or less, new motors are generally less expensive than rewinding. When standard-efficiency motors under 100 hp have failed, scrapping them is usually the most cost-effective option, provided that they have had sufficient run-time and are replaced with energy-efficient models.

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Nadel, Steven, et al., *Energy-Efficient Motor Systems: A Handbook on Technology, Programs, and Policy Opportunities*, American Council for an Energy-Efficient Economy, Washington, DC, 1991.

Drivepower Technology Atlas, E Source, Inc., Boulder, CO, 1996; (303) 440-8500; www.esource.com.

Contacts

FEMP offers training to facility managers on the use of *MotorMaster+* software and other motor system management topics. Contact the FEMP Help Desk at (800) DOE-EREC (363-3732), or see the FEMP Web site at www.eren.doe.gov/femp/.

MotorMaster+ 3.0 can be downloaded or used online: mm3.energy.wsu.edu/mmplus/.

DOE’s Motor Challenge Hotline, (800) 862-2086, provides information, software, and publications.

The Motor Challenge Web site, www.motor.doe.gov, includes discussion forums, frequently asked questions, and application information.

Electric motors vary greatly in performance. The selection of energy-efficient motors for HVAC equipment installed in renovation or new construction can result in greatly reduced energy consumption during their operational lifetimes. In converting electrical energy into mechanical energy, motors incur losses in several ways: electrical losses, iron (core) losses, mechanical (friction and windage) losses, and stray losses dependent on design and manufacturing. Energy-efficient motors reduce losses because of their better design, materials, and manufacturing. With proper installation, energy-efficient motors run cooler and thus can have higher service factors and longer bearing and insulation life.

Opportunities

Facility managers should consider installing energy-efficient motors when faced with any motor purchase or repair decision. Replacing a functional motor may be justified solely on the electricity cost savings derived from an energy-efficient replacement. This is especially true if the motor runs continuously, if electricity rates or demand charges are high, if the motor is significantly oversized for the application, or if its nominal efficiency has been reduced by damage or previous rewinds. Priority opportunities are HVAC fan motors and circulation pumps. Efficient motors for other uses should also be considered.

Any time motor replacement is being considered, attention should be paid to the loads served by the motor. Improvements to the overall *system* served by the motor may reduce its load. If this is done at the time of replacement, it may be possible to purchase a smaller, less expensive motor. If it is done independently of motor replacement, the motor may be oversized for the job, so efficiency will be lower.

Technical Information

The tips below relate to motor selection, maintenance, and possible rewinding or replacement.

MOTOR SELECTION

Manufacturers use many terms to describe their most efficient motors, including adjectives such as “high,” “super,” “premium,” and “extra.” These terms create confusion when comparing motors, so purchasers should always consult the nominal efficiency rating and the minimum efficiency rating. Nominal efficiency, an average efficiency of motors of duplicate design, is

listed in the manufacturer’s literature and in the *MotorMaster+* software. Even within the group of duplicate designs, there is some variation in actual efficiencies because of variations in motor materials and manufacturing. Minimum efficiency ratings can be used as the basis for the manufacturer’s guarantee.

To be considered energy-efficient, a motor must meet the performance criteria published by the National Electrical Manufacturers Association (NEMA). Most manufacturers offer lines of motors that significantly exceed the NEMA-defined criteria. Table 12-10 of NEMA (Standard MG-1) delineates efficiency “bins” that form the basis of the “NEMA nominal efficiency” ratings listed on nameplates. The bins provide ranges of efficiencies, such that actual nominal efficiencies are less than or equal to NEMA nominal efficiencies. For example, a motor with an actual nominal efficiency of 92.0 would have a nameplate efficiency listed as 91.7, since the NEMA bracket is 91.7, then 92.4. This standard applies only to Design A and B motors in the horsepower range of 1 to 500. The standard does not cover other sizes and designs, including C, D, vertical, and specialty motors.

Energy-efficient motors run cooler and therefore tend to last longer, and they may require less maintenance. Bearing grease lasts longer at lower temperatures, lengthening the required time between regreasing. Lower temperatures translate to longer-lasting insulation. Generally, motor life doubles for each 18°F (10°C) reduction in operating temperature.

A general guideline for selection of energy-efficient motors is to look for models that (1) have a 1.15 service factor and (2) are designed for operation at 85% of the rated motor load.

Speed control is crucial in some applications. In polyphase induction motors, slip is a measure of how efficiently a motor develops torque. The lower the slip, the higher the efficiency. Less slippage in energy-efficient motors results in speeds about 1% faster than in standard counterparts, which can increase energy use in fans and pumps.

Starting torque for efficient motors may be lower than for standard motors. Facility managers must be careful when applying efficient motors to high-torque applications.

MAINTENANCE

Inspect motors for misalignment or excessive vibration.

Inspect wires and connections on motors and incoming power for damage, corrosion, or looseness.

Check motor bearings and, on single-phase motors, check for wear on internal switches.

Clean dirt and grease from all motors and especially from the cooling fan and grill on totally enclosed, fan-cooled motors.

Check for electrical power problems that can affect the operation of energy-efficient motors. For example, plant personnel in one manufacturing operation blamed motor failures on the energy-efficient designs of their motors. However, further investigation revealed poor incoming power quality. Investigators suggested addressing the power quality instead of replacing the energy-efficient motors.

REPLACEMENT CONSIDERATIONS

Sizing motors is important. Do not assume that an existing motor is properly sized for its load, especially when replacing motors. Many motors operate



Facility managers can easily estimate operating savings of a high-efficiency motor compared with a typical motor (or an existing motor when replacement is being considered). The following formula is used to estimate the annual operating cost of a motor based on the efficiency at rated load, partial load factor (PLF) in percent, annual operating hours, and electricity rate (see calculation example at the bottom of this page):

$$\$/\text{year efficiency} = \text{hp} \times \text{PLF} \times 0.746 \text{ kW}/\text{hp} \times \text{hours}/\text{year} \times \$/\text{kWh}$$

Managers can also use the BestPractices Program's *MotorMaster+* software to estimate operating and energy savings. FEMP offers training to facility managers on the use of *Motor-Master+* software.

most efficiently at 75–85% of full-load rating. Undersizing or oversizing reduces efficiency. For large motors, facility managers may want to seek professional help in determining proper sizes and actual loadings. There are several ways to estimate actual motor loading: the kilowatt technique, the amperage ratio technique, and the less reliable slip technique. All three are supported in the *MotorMaster+* software.

Instead of rewinding motors, consider replacing them with an energy-efficient version, as even high-quality rewinding will result in some loss of efficiency. For larger motors, if motor rewinding offers the lowest life-cycle cost, select a rewind facility with high quality standards to ensure that motor efficiency is not adversely affected. For sizes of 10 hp or less, new motors are generally cheaper than rewinding. It is cost-effective to scrap most standard-efficiency motors under 100 hp when they fail, provided that they have had sufficient run-time and are replaced with energy-efficient models.

References

MotorMaster+ 3.0 can be downloaded or used online at: mm3.energy.wsu.edu/mmplus/.

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Contacts

BestPractices Program, Office of Industrial Technologies, U.S. Department of Energy; (800) 862-2086; www.oit.doe.gov.



Example of calculating energy cost savings from motor replacement: Consider replacing a 20 hp motor that operates 80% loaded for 8,760 hours per year where electricity costs 5.5 cents per kilowatt-hour. Assume efficiencies are 0.88 and 0.92 for standard and energy-efficient motors, respectively. Notice that this does not include savings from reducing electrical power demand.

Standard motor:	20 hp x 0.80 x 0.746 kW/hp x 8,760 hr/yr x \$0.055 per kWh / 0.88	=	\$6,535 per year
<u>Efficient motor:</u>	20 hp x 0.80 x 0.746 kW/hp x 8,760 hr/yr x \$0.055 per kWh / 0.92	=	<u>\$6,251</u> per year
Savings:		=	\$6,535 - \$6,251 = \$ 284 per year

Variable-frequency drives, a type of variable-speed drive, are controllers that vary the speed of induction motors. VFDs save substantial energy when applied to variable-torque loads, thus reducing electricity bills for most facilities. These energy savings are possible with variable-torque loads, such as fans and pumps, because torque varies as the square of speed, and horsepower varies as the cube of speed. For example, if fan speed is reduced by 20%, motor horsepower (and energy consumption) is reduced by 50%.

VFDs generate variable voltage and frequency output in the proper volts/hertz ratio for an induction motor from the fixed utility-supplied power. VFDs can be retrofitted into existing motor systems and can operate both standard and high-efficiency motors ranging in size from 1/3 hp to several thousand hp. Unlike mechanical or hydraulic motor controllers, they can be located remotely and do not require mechanical coupling between the motor and the load. This simplifies the installation and alignment of motor systems.

Opportunities

Variable-flow applications, where throttling or bypass devices are used to modulate flow, are good candidates for VFDs. These include centrifugal fans, pumps (centrifugal, impeller, or turbine), agitators, and axial compressors. The best applications for VFDs are large motors that can operate for many hours each year at reduced speeds. Some opportunities common in facilities include the following:

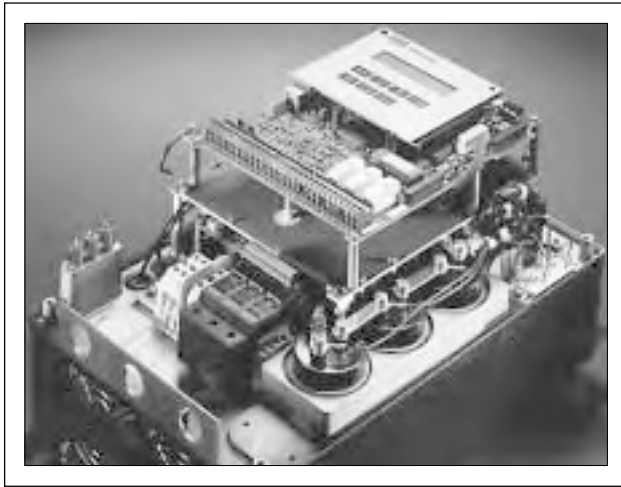
- **Variable-air-volume HVAC fans:** Airflow in older VAV systems is usually controlled by opening and closing dampers or inlet vanes. Because the systems often operate at low airflow, considerable energy savings are possible by converting to VFDs. VFDs vary motor speed in order to match fan output to varying HVAC loads, making dampers or inlet vanes superfluous.
- **Cooling tower fans:** Cooling towers may be good candidates for VFDs, because motors are large, fans often operate for long periods of time, and loads can vary both seasonally and diurnally.

- **Circulating water pumps for chillers and boilers:** Pumping systems can be made variable by sequencing fixed-speed pumps and a single variable-speed pump. This will save the cost of installing VFDs on each pump.
- **Special industrial applications:** The economics of using VFDs for applications such as grinding and materials handling, where precise speed control is required, depend on the size and run-time of the motors involved.

Technical Information

Three major VFD designs are commonly used: pulse-width modulation (PWM), current source inverter (CSI), and variable voltage inverter (VVI). A fourth type, the flux vector PWM drive, is gaining popularity but is considered too expensive and sophisticated for most applications. Knowing the characteristics of the load is critical in evaluating the advantages and disadvantages of each technology.

- **Pulse-width modulation** is the dominant VFD design in the 1/2 hp to 500 hp range because of its reliability, affordability, and availability. PWM outputs emulate sinusoidal power waves by varying the width of voltage pulses in each half cycle. Advantages of PWMs are low harmonic motor heating, excellent input displacement power factor, high efficiencies at 92–96%, and ability to control multiple motor systems with a single drive.
- **Current source inverter** designs are quite reliable because of their inherent current-limiting characteristics and simple circuitry. CSIs have regenerative power capabilities, meaning that CSI drives can reverse the power flow back from the motor through the drive. However, CSIs “reflect” large amounts of power harmonics back to the source, have poor input power factors, and produce jerky motor operations (cogging) at very low speeds. CSIs are typically used for large (over 300 hp) induction and synchronous motors.
- **Voltage source inverter** designs are similar to CSI designs, but VSIs generate variable-frequency outputs to motors by regulating *voltage* rather than current. Harmonics, power factor, and cogging at low frequencies can be problems.



This variable-frequency drive significantly improves overall energy efficiency.

Source: Alpha Electrical Service

VFDs should be properly installed to avoid damage to their electronics. This includes proper grounding, mounting, connection, voltage, and cooling. Improper installation and start-up accounts for 50% of VFD failures. **Precautions** for specifying, installing and operating VFDs are numerous.

- **Use the VFD start-up sheet** to guide the initialization check before energizing the VFD for the first time. If a VFD is started when the load is already spinning, the VFD will try to pull the motor down to a low, soft-start frequency. This can result in high current and a trip unless special VFDs are used.
- **Always install wall-mounted units** against a smooth, flat, vertical surface, or install a piece of plywood or sheet metal to create the required cooling channels. Installing VFDs intended for wall mounting as freestanding units will interfere with the “chimney effect” cooling of the heat sink.
- **Check and monitor motors operating at low speeds** because they can suffer from reduced cooling. For maximum motor protection on motors to be run at low speeds, install thermal sensors that interlock with the VFD control circuit. Standard motor protection responds only to over-current conditions.
- **Ensure that the power voltage** supplied to VFDs is stable within plus-or-minus 10% to prevent tripping faults.
- **Separate speed control wiring**, which is often 4 mA to 20 mA or 0 VDC to 5 VDC, from other wiring to avoid erratic behavior. Parallel runs of 115 V and 24 V control wiring may cause problems.
- **Prevent damage from corrosive environments**, humidity above 95%, ambient air temperatures exceeding 104°F (40°C), and conditions where condensation occurs, as much as possible.
- **If power switching is anticipated, include this capability in the specification.** Switching from grid power to emergency power while the VFD is running is not possible with most types of VFDs.
- **Interlock the run-permissive circuit to the disconnect** if electrical disconnects are located between the VFD and motor .
- **Use “inverter duty” motors** on new installations that will have VFDs.



If a motor always operates at its rated load, a VFD will *increase energy use, as a result of electrical losses in the VFD.*

References

ASDMaster™ software, EPRI PEAC Corporation, 942 Corridor Park Blvd., Knoxville, TN 37932; 800/982-9294; www.epri-peac.com/asdmaster/.

Murphy, Howard G., “Power Quality Issues with Adjustable Frequency Drive—Coping with Power Loss and Voltage Transients,” *Iron and Steel Engineer*, February 1994.

Induction motors, magnetic ballasts, and transformers require two types of power to operate. *Active power* (also called true or real power) produces work or heat, is used by all electrical devices, and is expressed in kilowatts. *Reactive power* is used by inductive devices to generate magnetic fields. It does not perform useful work and is expressed as kVARs (kilovolt-amps reactive). *Total power*, or apparent power, is the vector sum of active and reactive power and is expressed in kVA (kilovolt-amps). A *power factor* is the ratio of active power to total power and quantifies the portion of power used by a facility that does electrically useful work. Power companies generally charge an additional fee to facilities having power factors less than 85–95% in order to capture costs to the utility company that are not reflected by the electric energy (kWh) meter. Improving the power factor can increase current-carrying capacity, improve voltage to equipment, reduce power losses, and lower electric bills.

Opportunities

Efforts should be made to improve power factors if (1) power factors are below 90–95% and penalties charged by the electrical utility are high, (2) electrical problems within the facility can be eliminated by improving the power factor, or (3) installing larger transformers for capacity needs can be deferred. Power factor improvements should be considered whenever electrical equipment such as motors and lighting are being upgraded or replaced.

Technical Information

Electric motors are large contributors to poor power factors because many generally operate under light loads. Lower power factors do not necessarily increase peak kVA demand because of the reduction in load. For example, the power factor of an electric motor is lowest when the motor is lightly loaded. This occurs when both its power draw and contribution to the electrical peak demand is the least.

Power factor correction capacitors are designed to provide the reactive current needed by inductive loads. Capacitors may be installed to improve the power factor of a single load or an entire power system and come in sizes from 1 to 600 kVARs.

Automatic power factor correcting equipment switches banks of capacitors on- and off-line depending on the power factor. These may provide good solutions in applications where reactive loads vary in magnitude over time.

Locate capacitors upstream of motor controllers unless full-voltage, nonreversing, across-the-line starters are used.



Replace standard motors with energy-efficient motors that have high power factor ratings. Note that even high-efficiency motors will have poor power factors under low load conditions—and that efficiency is more important than power factor. Be sure not to sacrifice efficiency for power factor. Avoid operating equipment above its rated voltage. Minimize operation of lightly loaded or idling motors.

Shut down a lightly loaded motor in situations where a smaller, parallel motor can do the same job. For example, when chilled water demand drops, parallel pumps may be removed from service until loads increase.

Be aware that installing power factor correction capacitors on the load side of a motor-overload protection device may require reducing the overload size. The capacitor manufacturer will have tables to assist you in resizing.

Avoid oversizing capacitors installed on the load side of motor controllers because they can discharge into the motor when the controller is turned off. Damaging voltages may occur if kVAR current exceeds motor no-load current.

Note that power factor correction saves money in three basic ways:

- Avoided power factor penalties from the utility (where applicable).
- Freed capacity in supply transformers if such capacity is needed.



Photo: Northeast Power Systems, Inc.

This automated control and protection system includes capacitor banks and harmonic filter banks.

- Reduced I²R resistive losses in wiring, etc., provided the capacitors are located close to the inductive loads. Kilowatt-hour savings of less than 0.5% are typical, and savings of 1–2% would be the high range for typical commercial and industrial systems.



Beware of applications where there are significant harmonics (VFDs and other nonlinear loads). The harmonics can cause resonances with the capacitors and damage them. If harmonics exist, consider harmonic filters, which also typically improve power factor.

Do not exceed manufacturer's recommendation on maximum capacitor size.

Install high-power-factor lighting and electronic equipment. While motors garner most of the attention regarding power quality, lighting equipment and other electronic products can also have a significant impact on power factor. With lighting, ANSI classifies ballasts with power factors above 0.90 as “high power factor” (HPF). Magnetic ballasts often have far lower

power factors (0.50 is typical with some products), as do many types of office equipment (desktop computers, monitors, laser printers, etc.). When data on power factor are available, specify and buy high-power-factor products.



Power factor is less than one when energy is quickly stored and released in a piece of equipment so that the voltage and current are out of phase by the angle Θ .

$$\text{Power factor} = \frac{\text{watts}}{\text{volts} \times \text{amps}} = \text{Cos } \Theta$$

Additional power is not consumed, but bigger wires and transformers are required to handle the additional amps needed by the load. Low power factors of large inductive loads, such as motors, can be improved by adding capacitors to the load. Current through a capacitor has the effect of cancelling out the lagging current.

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Elevators consume a significant fraction of the total energy used in tall buildings. In low-rise and mid-rise buildings, their energy use is less substantial, but opportunities for improving conventional practices are huge. In addition to reducing energy use, newly selected elevators should minimize other environmental concerns, such as the potential for leaking hydraulic fluid, maintenance requirements, and future replacement cost.

The electricity-consuming elements of elevators are the drive/machine, car illumination (some elevator codes require this to be on all the time), and the controller. Though the illumination in infrequently used elevators can equal the drive consumption, in 99% of cases the drive is the dominant consumer.

Opportunities

The greatest opportunity to select lost-cost, high-performance elevators is early in the design process for a new facility, because the type of elevator selected can significantly affect the space and structural requirements of the hoistway and ancillary spaces. Any time equipment needs replacing or significant maintenance, however, upgrading to more energy-efficient and environmentally friendly systems should be considered. Elevators in high-rise buildings use significant amounts of energy, so even marginal improvements in their efficiency can translate into significant savings. The most significant improvement opportunities exist in low-rise buildings because the hydraulic elevators typically installed in these facilities are the least efficient and the most problematic in terms of pollution from hydraulic fluid. Switching to a less toxic hydraulic fluid should be considered for buildings with hydraulic systems that are not candidates for replacement.

Technical Information

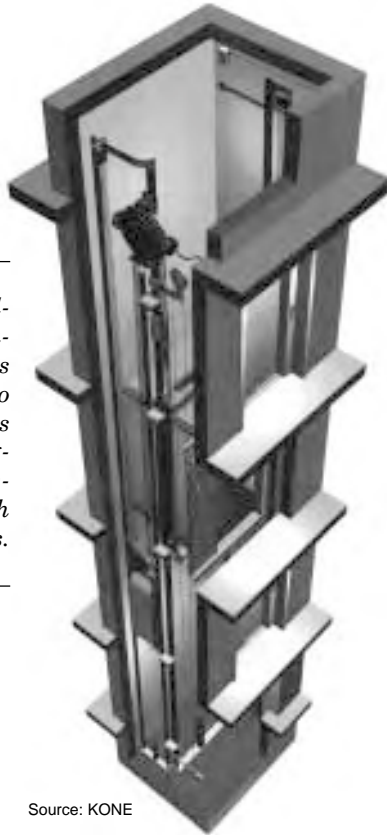
Good data on the fraction of a building's energy use represented by elevators is sparse, but a typical estimate is 4–10%. A recent survey of ten high-rise residential buildings by Canada Mortgage and Housing Corporation found that the elevators' share in overall energy use was 3–9%. As with lighting, all energy used by elevators is converted into heat, so excess energy use translates into increased cooling loads as well. Elevator shafts can also be significant sources of lost heat in cold climates, due to poor airtightness and the strong upward pressure of hot air, or the stack effect.

Elevator technology is a highly specialized field, with many factors affecting comfort, safety, energy efficiency, and maintenance requirements. In very general terms, elevators for low- and mid-rise buildings are typically either hydraulic or traction (gear-driven) systems, while high-rise buildings use variable voltage-variable frequency (VVVF) controlled gearless AC-motors replacing earlier DC technology. A more recent evolution is the availability of VVVF systems for low- and mid-



Hydraulic elevators tend to increase in cost roughly in proportion to the number of stops. More sophisticated elevators, on the other hand, are only incrementally more expensive with each added stop. Consequently, in low-rise applications, high-performance elevator systems tend to cost significantly more than hydraulics do. Other factors affecting the cost comparison include the reduced cost for electrical supply and connections when the elevator's maximum draw is reduced by two-thirds. Selecting a system that does not require a machine room also reduces the cost.

In the EcoSystem elevator a thin, permanent magnet motor is mounted directly to the hoisting rail. This technology offers significant energy savings compared with conventional systems.



Source: KONE

rise applications, which makes the energy efficiency and comfort of that technology available to buildings that are not so tall.

While the initial cost of hydraulic elevators makes them typically the least expensive for short runs, their inefficiency and the potential for groundwater contamination from leaking hydraulic fluid make them less desirable environmentally. Conventional hydraulic elevators require that a shaft be drilled in the ground that is equivalent in depth to the height of the lift. Modified systems use a telescoping shaft or a hydraulic lift with cables to avoid the complications of the long, in-ground shaft. In addition, less toxic, vegetable-based hydraulic fluid—although costly—is available to reduce the risk of ecological and health damage.

The latest VVVF technology with a permanent-magnet, synchronous motor also offers the possibility of saving space and construction costs because, up to certain elevator load/speed values, the small motor actually fits inside the hoistway. When mounted directly on the main car guiderails, this design avoids the need for a separate machine room and reduces the structural demand on the building because the guiderails support the load of the moving car. Initially introduced only for smaller applications, this guiderail-mounted motor technology is now expanding into longer runs and larger sizes, including freight elevators.

Any elevator system with significant traffic can also benefit from a control system that provides the most cars where they will be needed while reducing unnecessary travel. Some manufacturers now offer sophisticated computerized controls capable of optimizing energy consumption in addition to reducing response and travel time, including systems based on fuzzy logic that self-adjust based on travel patterns. Simpler controls can be programmed to cut off power to some cars during low-usage periods, reducing standby energy use. Finally, cab lighting can be a large factor, as these lights are usually on all the time. Higher-efficiency lamps often also have longer service lives, which reduces the labor cost associated with lamp replacement.

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“New energy-efficient lift concept,” from CADDET Energy Efficiency, a program of the International Energy Agency and the Organization for Economic Cooperation and Development; www.caddet-ee.org/techbroc/r314.htm.

“EcoSystem: A Better Elevator,” *Environmental Building News*, Vol. 8, No. 7/8, p. 7, July/August 1999; BuildingGreen, Inc., Brattleboro, VT; (800) 861-0954. This review is posted on the BuildingGreen Web site: www.BuildingGreen.com.

Electricity is the largest energy source in most facilities, powering HVAC equipment, motors, lighting, water heaters, and all types of industrial, office, and residential appliances and equipment. Electricity is generated primarily from fossil fuels and nuclear power sources, which have high pollution burdens. Only about one-third of the energy in the source fuels is delivered to the end user as electricity; the rest is lost to inefficiencies in generation and transmission of the power. With deregulation of the electric utilities, many new procurement options are becoming available, including the possibility of buying green energy from non-polluting, renewable sources. The focus of this section is on procuring electricity from green sources and on ways to transfer it efficiently from delivery point at the facility to points of use. Further analysis of power systems is presented in *Section 5.8.1*, transformers are addressed in *Section 5.8.2*, and combined heat and power is addressed in *Section 5.8.8*.

Opportunities

Evaluate the pollution burden associated with electricity that a facility is using or considering for purchase, and seek opportunities to purchase green power. Consider the efficiency, reliability, and maintenance requirements of power systems whenever installing, renovating, or replacing equipment. There are opportunities within the facility's distribution system to save energy, increase equipment life, and reduce unscheduled outages. In some cases, efficiency improvements may be significant enough to justify replacement even if current equipment is still serviceable.

Technical Information

Efforts to reduce the environmental impact of electricity systems at any facility should include two parallel efforts: improving utilization efficiency on site and procuring green power.

UTILIZATION EFFICIENCY

Electric utility bills include both energy charges in kilowatt-hours and power demand charges in kilowatts. Rates may vary by season and time of day. Opportunities for improving the efficiencies of electrical power systems include evaluating and correcting voltage imbalances, voltage deviations, poor connections, undersized conductors, poor power factors, insulation leakage, and harmonics. Components to check in a maintenance program include transformers, conductors, switchgear, distribution panels, and connections at loads and elsewhere. Utilities penalize facilities with low power factors that require the utility to provide power-factor compensations.

Voltage imbalances are problematic differences between relative voltage levels among the three phases in part or all of a facility. Voltage imbalances result in preventable energy waste, excessive equipment wear, and premature equipment failure. Power demands on all three power phases should be virtually equal in order to maintain equal voltages in all phases. Problems with conductors, connections, and transformer settings may cause imbalances in any facility; however, supplying single-phase needs while maintaining three-phase balance is a challenge.



Avoid imbalance in supply circuits by distributing single-phase loads such as lighting, single-phase motors, resistance heating, and plugloads among phases.

Designate or hire a Resource Efficiency Manager who will find and address power imbalances, suboptimal equipment, and other inefficiencies. The more critical the equipment, the more maintenance resources should be devoted to it. Maintenance programs for electrical distribution systems may be reactive, preventive, predictive, or proactive. With good recordkeeping, a manager can develop the tools needed for at least a predictive if not a highly proactive maintenance program.



Photo: Warren Gretz

This substation at the Palm Springs wind farm ties wind-produced electricity into the power grid.

GREEN POWER

The restructuring of the electric utility industry has created an opportunity for companies to offer electricity from renewable and nonpolluting sources to customers in states that have embraced deregulation. In many other states, where utilities are still regulated, green pricing is available as an option for customers who wish to pay a premium to support clean electricity sources. Executive Order 13123 directs Federal agencies to include provisions for the purchase of electricity from renewable energy sources in their

MAINTENANCE TYPE AND PHILOSOPHY

REACTIVE: Repairs are made or components are replaced only upon failure.

PREVENTIVE: Includes inspecting, diagnosing, and servicing electrical systems to minimize future equipment problems or failures.

PREDICTIVE: Uses tests to predict the required service intervals, and targets equipment with the greatest service needs.

PROACTIVE: Employs failure analysis and predictive analysis as feedback to improve maintenance practices.

requests for bids whenever procuring electricity. A number of funding mechanisms are available to pay the premium associated with green power. See FEMP's Utility Market Restructuring Web site for current information.

Because of the complex nature of the electric transmission and distribution system, and the varying definitions of "green" and "renewable" energy, there has been some confusion and misinformation in the green electricity marketplace. In response to this problem, the Center for Resource Solutions, a San Francisco-based nonprofit organization, has developed the Green-e Renewable Electricity Program to certify green power providers that meet its criteria. Green electricity providers being considered for a contract should be accredited as such by the appropriate state board and should carry the Green-e certification. The Center for Resource Solutions also has a parallel program to accredit green pricing programs from regulated utilities.

References

Total Efficiency Network, Washington State University Energy Program; (888) 634-2558; www.energy.wsu.edu/ten/.

FEMP's Utility Market Restructuring Web site: www.femp-restructuring.org/.

Contacts

Center for Resource Solutions, Presidio Building 49, P.O. Box 29512, San Francisco, CA 94129; (415) 561-2100, (415) 561-2105 (fax); www.resource-solutions.org.

Analysis of electrical power systems may uncover energy waste, fire hazards, and impending equipment failure. A well-executed analysis requires planning and lays the foundation for ongoing reliability-based maintenance.

Opportunities

The best time to initiate preventive maintenance on electrical systems is before failures occur. Regular maintenance will help uncover hidden problems, allow timely repair, and avoid the unexpected disruption of system failure. In a new facility, maintenance should begin from the outset. In existing facilities, it is never too late to start a regular electrical system maintenance program.

Technical Information

“Tune-ups” for electrical power systems yield both direct and indirect efficiency improvements, and they can increase the reliability of equipment. Direct improvements result from correcting leaks to ground and cutting resistive (I^2R) losses in the distribution components. Indirect improvements result from improving the efficiency of equipment that previously operated with poor quality input power, such as three-phase motors operating with phase-to-phase voltage imbalances.

Establish a preventive maintenance program that includes good recordkeeping. The following procedures should be followed when possible:

- Document system components and electrical loads. Start with available drawings and other documentation. Update this documentation to “as-built” and keep files current.
- Inspect components, noting discoloration, deformation, damage, hot odors, noise, or vibration.
- Manually operate all switches and disconnects on a monthly schedule to help eliminate corrosion.

- Conduct a regime of electrical tests designed to identify actual and potential problems. This may include contact condition assessment with a voltage-drop survey, infrared thermography, power factor assessment, or voltage assessment to determine imbalances and deviations from target voltages.
- Consider a proactive maintenance program with the predictive elements discussed in *Section 5.8 – Electrical Power Systems*.



When conducting electrical assessments, be aware of varying conditions. Power quality may change greatly at night or at other times because of changes in loads.



Facility managers increasingly find that reliability-centered maintenance can save money, reduce energy consumption, and reduce downtime. A lumber/plywood facility in Oregon projected \$125,000 in potential savings by instituting an electrical system preventive maintenance program. Estimating actual savings is difficult, however, because of the uncertainty about when failures will occur, what equipment will be damaged, and how long problems will last.

References

IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems (ANSI/IEEE Standard 242-1986), Institute of Electrical and Electronics Engineers, 1986; Publications Office, Los Alamitos, CA: (800) 272-6657; www.ieee.org.

Keeping the Spark in Your Electrical System: An Industrial Electrical Distribution Maintenance Guidebook (WSEO 93-15), Washington State Energy Office, Olympia, WA, 1995.



Source: FLIR Systems

Infrared thermography can quickly identify electrical power system problems and should be included in a proactive maintenance program. Apart from the costly inefficiency of wasted power, this faulty electrical connection would eventually have resulted in total failure once the melting point was reached.

TROUBLESHOOTING FOR POWER SYSTEMS

PROBLEM	COMMON CAUSES	POSSIBLE EFFECTS	SOLUTIONS
Voltage imbalances or differences between relative voltage levels among the three phases in all or part of a facility	Improper transformer tap settings, one single-phase transformer on a polyphase system, single-phase loads not balanced among phases, poor connections, bad conductors, transformer grounds or faults	Motor vibration, premature motor failure, energy waste (a 5% imbalance causes a 40% increase in motor losses)	Balance loads among phases.
Voltage deviations (voltages too low or high)	Improper transformer settings, incorrect selection of motors, e.g., a 230/208 motor (which is actually 230-volt rated) on a 208-volt circuit	Reduced efficiency, power factor, and equipment life; increased temperature	Check and correct transformer settings, motor ratings, and motor input voltages.
Poor connections (may be in distribution or at connected loads)	Loose bus bar connections, loose cable connections, corroded connections, poor crimps, loose or worn contactors, corrosion or dirt in disconnects	Energy waste, heat generation, failure at connection site, voltage drops or imbalances	Use IR camera to locate hot-spots and correct.
Undersized conductors	Facilities expanding beyond original designs, poor power factor	Voltage drop, energy waste	Reduce the load through conservation load scheduling.
Insulation leakage	Degradation over time due to extreme temperatures, abrasion, moisture, chemicals, or use of conductor insulation inappropriate for conditions	Breaker trip failure, current leakage to ground or to another phase, variable energy waste	Replace conductors, insulators.
Low power factor	Inductive loads such as motors, transformers, and lighting ballasts; nonlinear loads such as most electronic equipment loads	Reduction in current-carrying capacity of wiring, voltage regulation effectiveness, and equipment life; increase in utility costs	Add capacitors to counteract reactive loads (see <i>Section 5.7.3 – Power Factor Correction</i>).
Harmonics (nonsinusoidal voltage and/or current wave forms)	Office electronics, telephone PBXs, uninterruptible power supplies, variable-frequency drives, high-intensity discharge lighting, and electronic and core-coil ballasts	Overheating of neutral conductors, motors, transformers, switch gear; voltage drop, low power factors, reduced capacity	Choose equipment carefully. Isolate sensitive electronics from noisy circuits.

5.8.2 Transformers

Customer-owned transformers allow facilities to purchase power at lower costs and then step down electric utility power distribution line voltages to lower secondary voltages needed for internal applications. Transformers commonly used for powering large facilities are either liquid-filled, dry-type, or epoxy cast resin. Liquid-filled transformers may be pole-mounted for overhead distribution, pad-mounted for underground feed in and out, or station-class for lineup application with switchgear. Dry-type transformers are used both in medium-voltage applications, such as substations, and in low-voltage (less than 600-volt primary) step-down applications, such as plugloads and lighting. Dry-type transformers are typically located inside buildings away from harsh environments. Proper transformer selection is important to ensure robust application and to minimize the potential for catastrophic failure. Energy efficiency considerations are particularly important and can result in rapid recovery of incremental investments.

Opportunities

Purchase energy-efficient transformers and practice good installation techniques whenever replacing or adding new equipment. Conduct proactive transformer maintenance along with other electrical maintenance functions.

Technical Information

Efficiencies of low-voltage dry-type transformers, designed only for temperature rises, will range from 95% to 98%, with core losses caused by magnetizing and coil losses caused by impedance and resistance. NEMA Standard TP 1-1996 was established to define energy-efficient liquid and dry-type transformers. TP 1-compliant transformers will range from a low of 97.0% efficiency for 15 kVA dry-type to 98.9% efficient for 1,000 kVA low-voltage dry-type. Medium-voltage dry-type transformers, designed to meet the NEMA Standard, will range from 96.8% efficiency at 15 kVA to 99.1% efficiency at 2,500 kVA. Low-voltage dry-type transformers meeting the TP 1-1996 requirements also qualify for an ENERGYSTAR® label. When purchasing transformers, look for those with high efficiency ratings that meet your needs. Be sure to obtain all transformer loss information from the manufacturer and match the transformer to the load profile. Manufacturers trade off coil losses (most significant at full load) with core losses (most significant at low load). Consequently, a low-temperature-rise unit that operates very efficiently at high load may be inefficient at low load.



Each year, according to insurance industry figures, more than 100 incidents of electrical and fire damage are caused by inadequate transformer maintenance, resulting in \$10 million in losses.

Disconnect the primary side of transformers not serving active loads. Transformers consume power even when loads are switched off or disconnected. Disconnecting the primary side of transformers to reduce transformer standby losses is safe, provided that critical equipment such as clocks, fire alarms, and heating control circuits are not affected.

For three-phase transformers, ensure that the voltage of each phase is balanced with others to within the minimum transformer step. If this fails to yield equal tap settings, redistribution of the loads is needed.



Though not particularly glamorous in appearance, this Honeywell TranStar, the first ultra-low-loss transformer available in North America, achieves 98.5% efficiency at 35% load unit and could save users up to \$3,500 each year.

Source: Honeywell

Reduce acoustical noise from pad-mounted transformers through proper design. In areas where personnel might be affected by the 60 Hz hum of power transformers, use isolators to reduce transmission to the building's structural components. Install isolators between the transformer core and housing, and also between the housing and the building structure.

Visually inspect transformers to verify that oil is contained and that connections appear to be sound.

Scan temperatures of transformers using infrared thermography to determine points of energy waste and pending failure. Criteria for assessment include ambient air temperature, rated-rise of similar transformers under the same conditions, and an absolute maximum allowable temperature.

Maintain balanced voltage with polyphase transformers by maintaining equal tap settings. Balance single-phase loads among phases to keep voltages within 1% of the average.

Be careful when connecting single-phase transformers to a three-phase system. If the load is large, a three-phase transformer should be used and the single-phase loads should be balanced.

Cooling oil in old transformers may contain polychlorinated biphenyls. PCBs are hazardous, cancer-causing agents that must not be released into the environment. Use extreme care to avoid spillage when replacing PCB-containing transformers. Collect oils for recycling or disposal at an approved hazardous waste facility. Follow applicable safety and environmental protection standards for handling and disposal.

References

Guide for Determining Energy Efficiency for Distribution Transformers. NEMA Standards Publication TP 1-1996, National Electrical Manufacturers Association (NEMA), Rosslyn, VA; www.nema.org.

"Honeywell TranStar Transformer Offers Significant Savings," *Environmental Building News*, Vol. 9, No., 7/8, July/August 2000; BuildingGreen, Inc., Brattleboro, VT; (800) 861-0954; www.BuildingGreen.com.

Contacts

Consortium for Energy Efficiency, Inc., One State Street, Suite 1400, Boston, MA 02109; (617) 589-3949; www.CEEforMT.org.

U.S. Environmental Protection Agency ENERGY STAR Program; (888) STAR-YES; www.epa.gov/appdstar/transform/.

5.8.3 Microturbines

Microturbines are emerging as a very promising technology for power generation at the scale of 25 to 300 kW. A handful of companies have introduced—or will soon introduce—these small, self-contained gas-turbines for utility distributed-power applications and self-contained power systems at manufacturing plants, hospitals, data processing centers, and other commercial-scale facilities.

Opportunities

Microturbines should be considered for power generation in the following situations:

- When the reliability of the power supply is extremely important;
- When grid-supplied power is limited or very costly (whether from kWh usage, time-of-use, or demand charges);
- When power quality is a concern either because of problems with grid-supplied electricity or because of particular needs for the facility;
- When utility companies require distributed generation capacity to meet remote power-user demands; and
- When thermal energy needs (for heating, absorption cooling, water heating, and industrial processes) can be matched with electricity generation.

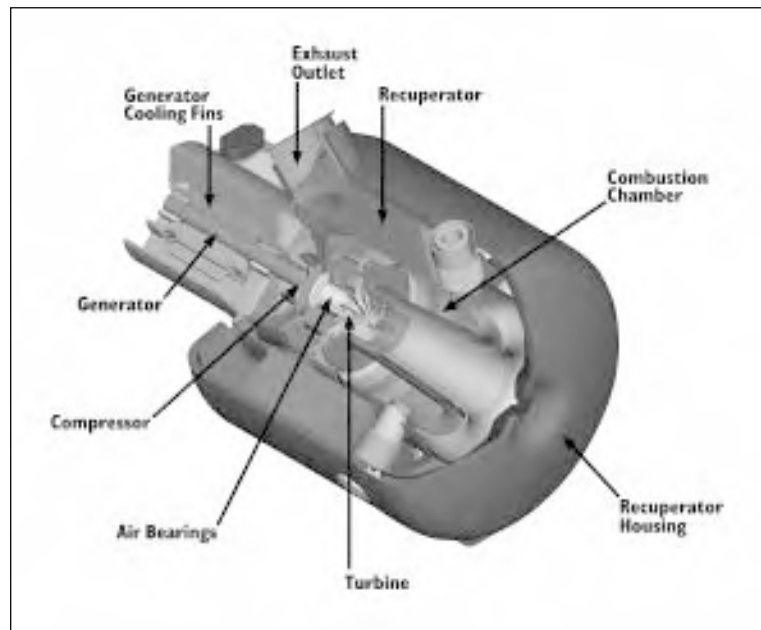
Microturbines like this work like jet engines but produce electricity instead of thrust. Capstone's products have one moving part and operate with air bearings.

From an environmental standpoint, the potential of producing both heat and electricity—combined-heat-and-power (CHP) or cogeneration—with microturbines is particularly exciting. CHP systems provide an opportunity to dramatically increase the overall efficiency of delivered energy—by 25–30% with the microturbine alone to well over 50% when waste heat is utilized.

Technical Information

Microturbines, or turbogenerators as they are sometimes called, evolved out of turbocharger technology that is used to boost power output in cars, trucks, propeller-driven airplanes, and jet aircraft. The first microturbines were developed in the 1960s by Allison Engine Company (a division of Rolls-Royce) and used on a test basis to power several Greyhound buses. The fuel (usually natural gas, but also such fuels as propane, methane, landfill gas, gasified biomass, gasoline, and diesel) is superheated and burned. Combustion gases power a turbine, spinning the shaft extremely rapidly—up to 100,000 revolutions per minute (rpm). This spinning shaft, in turn, powers a high-speed generator, producing electricity. Waste heat can be extracted from the exhaust and used. However, current microturbines offer no improvements in efficiency or emissions over larger turbines.

While the commercialization of microturbines is just beginning, the Gas Technology Institute expects com-



Source: Capstone Turbine Corporation



Source: Capstone Turbine Corporation

The Underwriters Laboratory (UL)-rated Capstone MicroTurbine™ Model 330 produces 25–30 kW of electricity and can be configured for cogeneration.

mercial products to have an operating life of 25,000 to 50,000 hours, very low polluting emissions (nitrous oxide [NO_x], levels of 9 to 42 parts per million), and a purchase price of \$600 to \$1,200 per kW. Unlike most of the larger gas turbines used for utility power generation that are custom-made for the application, microturbines will be mass-produced, off-the-shelf items. They are being designed to have very few moving parts (often only one!), in comparison to the many hundreds of parts for reciprocating engines that have generally served this power-generation market. The simple design and the use of air bearings contribute to quiet operation—typically less than 70 dB at 10 feet (3 m)—and long service life between overhauls. The use of ceramics in turbine manufacture may further improve durability and performance in the future.

Among the active developers of microturbines are Honeywell (previously AlliedSignal Power Systems), Capstone Turbine Corporation, Allison Engine Company, NREC Energy Systems (a division of Ingersoll-Rand Co.), and Elliot Energy Systems (which is teaming up with GE Power Systems and NICOR). Among the first products to be introduced, the Capstone MicroTurbine™ Model 330 burns natural gas and produces 25–30 kW at approximately 27% efficiency with less than 9 ppm of NO_x. The 1,050-pound (476 kg) unit stands just over 6 feet (1.8 m) tall and looks somewhat like an oversized computer (see photo).

TINY MICROTURBINES

Another class of microturbines—very small units with outputs sometimes measured in watts rather than kilowatts—is being developed primarily for military applications. These units will provide portable power to soldiers for radios, GPS equipment, and battlefield computers. Going the furthest with this concept, the Massachusetts Institute of Technology has designed a tiny, flat microturbine under 1/2 in. (12 mm) in diameter, 1/8 in. (3 mm) long, and weighing just a gram, with a turbine speed of 1.4 million rpm, fuel consumption of a gram per hour, and output of 10 to 20 watts! As these products evolve, they may find applications in houses and small commercial buildings. A shoebox-sized microturbine might someday be able to power a house and heat its water.



The Gas Research Institute projects that microturbines will cost \$600 to \$1,200 per kW to install. Some other organizations project costs as low as \$225 per kW, with a delivered electricity cost below 5¢ per kWh, including amortized equipment costs. For facilities with time-of-day electricity pricing or high demand charges, microturbine costs can be repaid much more quickly than the 5¢/kWh cost might imply. Using cogenerated heat can further improve the economics of microturbines.

Contacts

Distributed Power Coalition of America, 10 G Street, NE, Suite 700, Washington, DC 20002; (202) 216-5944, (202) 216-0874 (fax); www.dpc.org.

Advanced Turbine Systems Program, Office of Industrial Technologies, U.S. Department of Energy, Washington, DC; OIT Resource Center: (202) 586-2090; www.oit.doe.gov/cogen/.

Energy Conversion Program, Gas Technology Institute (formerly Gas Research Institute), 8600 W. Bryn Mawr Avenue, Chicago, IL 60631; (773) 399-8352, (773) 864-3551 (fax); www.gri.org.

5.8.4 Fuel Cells

Fuel cells generate electricity by converting chemical energy into electrical power with few moving parts. Power generation by means of fuel cells is a rapidly emerging technology that provides electricity with high efficiency and little noise. Fuel cells produce no noxious gases that produce acid rain, no particulate pollutants that foul the air, no unburned hydrocarbons during normal operation, and proportionately less carbon dioxide (CO₂) than other, less efficient technologies. Fuel cells provide the opportunity to make the transition from fossil fuels, such as natural gas, methane, and liquid hydrocarbons, to what many consider to be the fuel of the future: hydrogen.

Opportunities

At costs up to \$3,000 to \$4,000 per kW, fuel cells are not for everybody. While DOD and others estimate that the installed cost of a fuel cell will have to drop to \$1,500 per kW before they will be widely used for most applications, they are already cost-effective in situations where very clean power and reliable backup energy supplies are essential. Fuel cells generate cleaner power than is generally available from the utility grid, so facilities with equipment that is sensitive to current and voltage variations can use fuel cells effectively. Hospitals, data centers, and other mission-critical facilities can obtain fuel cells to provide emergency power and then use them to meet a portion of their everyday base load as well. Remote sites without access to the utility grid are also good candidates for fuel cells. Facilities that can make effective use of waste heat can use that free energy to help offset the devices' higher cost.

Technical Information

Fuel cells are electrochemical engines that convert the chemical energy of a fuel and an oxidant—hydrogen and oxygen—directly into electricity. The oxygen used in the fuel cell is atmospheric oxygen, and the hydrogen is either elemental hydrogen or hydrogen extracted from hydrocarbon fuels using a device called a *reformer*. Water is the only significant by-product of a fuel cell's operation. Because nearly all fuel cells in use or under development today rely on hydrocarbon fuels as their source of hydrogen, however, CO₂ and other air pollutants are emitted from the reformer.

The fuel cell's principal components are catalytically activated electrodes for the fuel (anode), the oxidant (cathode), and an electrolyte to conduct ions between the two electrodes. Because the operating conditions of the fuel cell are largely determined by the electrolyte, fuel cells are classified by the type of electrolyte.

Four leading fuel cell technologies are being developed at present:

Phosphoric acid fuel cells (PAFC) have an acid electrolyte and are the most highly developed fuel cells. These operate at relatively low temperatures, around 400°F (200°C), are commercially available, and have thermal output that can be used in cogeneration applications. DOD has been testing 200-kW PAFCs at various facilities since 1993, with generally positive results (see box, next page). The first 1-MW system is currently installed and being tested at a U.S. Postal Service mail distribution center in Anchorage, Alaska (see photograph).

Proton exchange membrane (PEM) fuel cells are well suited to residential, light commercial, and mobile applications requiring relatively compact power systems. The electrochemistry of PEM fuel cells is similar to that of phosphoric acid fuel cells. They operate in the same pressure range but at a much lower temperature, about 175°F (80°C). Their very low thermal and noise signatures may make them especially useful for replacing military generator sets.

Fuel cells using a **molten carbonate** (MCFC) electrolyte are relatively high-temperature units, operating at higher than 1100°F (600°C). Current MCFCs are being designed for applications on the order of 250 kW to 5 MW. The high-temperature exhaust gases can be used in a combined-cycle (cogeneration) system, creating an overall efficiency of about 80%.

Solid oxide (SOFC) electrolyte fuel cells are also high-temperature devices, operating at 1100 to 1800°F (600 to 1000°C). At these temperatures, a natural gas-powered fuel cell does not require a reformer. The solid construction of the SOFC fuel cell prevents some of the corrosion problems of liquid-electrolyte fuel cells. SOFC cogeneration power systems are expected to provide electric power at efficiencies close to 50% and useful steam or hot water at about 40% of rated power, raising the overall effectiveness of the system. A variety of 20- to 125-kW SOFC units have been tested, and units up to 1 MW are planned for preproduction release.

The U.S. Postal Service distribution center in Anchorage, Alaska, is powered by five 200-kW fuel cells as part of the DOD Fuel Cell Demonstration Program.

Fuel cells are inherently less polluting than conventional fossil-fuel technologies and are more efficient in producing electricity. They produce almost no harmful air or water emissions. The principal by-product is water. However, PAFC, MCFC, and PEM fuel cells have inherent maintenance problems related to water issues. Make-up water supply is required, and—depending on the mineral content—a water treatment system may also be required.

The footprint of a 200-kW PAFC unit is about 200 ft² (20 m²), while the footprint of a 2.85-MW MCFC plant is about 4,500 ft² (450 m²). For many types of fuel cell power plants, stack and fuel processor units must be replaced every 5 to 10 years, requiring a shutdown of several days. Current cost estimates for this are up to half the cost of the fuel cell plant.

References

Fuel Cells for Buildings program; U.S. Department of Energy; www.pnl.gov/fuelcells/.

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Contacts

Facilities Division, Energy Branch, U.S. Army Construction Engineering Research Lab; (217) 373-7214; www.dodfuelcell.com.

Electrochemical Technology Program, Argonne National Laboratory, U.S. Department of Energy; (630) 252-2000; www.anl.gov.



Source: U.S. Postal Service



DOD Fuel Cell Demonstration Program:

Since Fiscal Years 1993 and 1994, the U.S. Army's Construction Engineering Research Laboratory has overseen the installation and operation of 30 PAFC fuel cells made by ONSI Corporation at facilities across the nation. Installation and maintenance were included in the contract, thus providing an opportunity for ONSI to learn how its units work in the field. This process has led to several refinements to ONSI's standard PA25 fuel cell.

As of April 1, 2000, the 30 fuel cells had generated a total of 95,000 MWh of electricity and provided 181×10^9 Btu in thermal energy. The displaced cost for this energy is \$3.8 million. Avoided air emissions include 182 tons of nitrous oxides, 390 tons of sulfur oxides, and 15 tons of carbon monoxide. DOD is considering following this program with tests of several other fuel cell technologies.

5.8.5 Photovoltaics

Photovoltaic, or PV, cells are semiconductor devices that convert sunlight into electricity. They have no moving parts. Energy storage, if needed, is provided with batteries. PV modules are successfully providing electricity at hundreds of thousands of installations throughout the world. Especially exciting are building-integrated photovoltaic (BIPV) technologies that integrate PV directly into building materials, such as semitransparent insulated glass windows, skylights, spandrel panels, flexible shingles, and raised-seam metal roofing.

Opportunities

Photovoltaic systems are cost-effective in small applications removed from utility power. It costs less to serve a small load with PV than to install a power line, even on a first-cost basis. PV prices have historically declined about 5% per year, and PV systems are typically less expensive than operating a stand-alone generator in a remote location. Consider replacing small (less than 10 hp) generators with PV, especially in environmentally sensitive areas where maintenance and fuel spills are a concern. Increasingly, PV is being considered as a source of electrical energy for buildings—even those with ready access to utility power—with the PV system integrated into the building envelope.

Technical Information

At the heart of all PV systems is the photovoltaic cell. *Crystalline PV cells* are made from thin circular or rectangular silicon wafers sliced from single-crystal or polycrystalline silicon stock. Wafers are doped either with boron or phosphorus to provide them with special charge properties and are sandwiched together to create cells. Most crystalline PV cells are on the order of 8 to 17 mils thick and typically 12–14% efficient.

With thin-film PV cells, the semiconductor material is deposited directly onto a glass, plastic, or metal substrate in a very thin layer (usually less than 5 microns thick), thus dramatically reducing the amount of material used. Thin-film cells are produced today with one to three layers of amorphous (noncrystalline) silicon, very thin layers of crystalline silicon, or more exotic materials such as cadmium telluride or copper indium diselenide. Most thin-film PV cells are 5–10% efficient in converting sunlight to electricity.

Modules are produced by wiring PV cells together and sealing them between layers of protective materials—usually glass. For BIPV applications, crystalline cells can be custom-colored (standard colors are dark gray to deep blue) and spaced to allow light transmission between cells, and modules can measure up to about 30 sq ft (2.8 m²) in area. Thin-film modules typically

are a uniform gray color and can be semitransparent.

Modules, in turn, are assembled into *PV systems*, which can be either stand-alone or utility-interactive, as described below.

STAND-ALONE PV SYSTEMS

Stand-alone PV systems can be set up to function in several ways:

- **A direct-coupled system** is the simplest version and consists of photovoltaic cells driving a DC load with no battery storage. Loads such as water pumps, ventilation fans, and special DC refrigerators are good applications.
- **Battery storage systems to drive DC loads** store the PV-produced energy until it is needed—for example, to power navigation aids at night. The simplest version drives DC loads only and requires a battery with charge control to prevent overcharging.
- **Battery storage systems to drive AC loads** have a charge controller and an inverter (which changes DC to AC) to power connected AC loads. Hybrid systems may have one or more additional energy sources, such as a wind turbine or diesel generator.

Typical stand-alone applications include remote residential lighting and home power, emergency communications, irrigation systems for agriculture, microwave repeaters, cathodic protection for bridges and pipelines, navigation aids, security systems, meteorological stations, remote area lighting, and signboard lighting. There are hundreds of thousands of stand-alone PV systems worldwide.

UTILITY-INTERACTIVE PV SYSTEMS

Utility-interactive or grid-connected systems require an interactive inverter to operate with the grid. The PV power is first delivered to the load, and then extra electricity is sent to the grid. The inverter matches the output power to the phase and frequency of the grid. Some considerations are as follows:

- **Net metering**, legislated in a majority of states for residential-scale systems, allows the electric meter to literally spin backwards, giving full retail credit for electrical energy exported to the grid.
- **The Public Utilities Regulatory Policy Act (PURPA)** requires utilities to interconnect to any qualified facility. However, the facility must pay for the interconnection.
- **Technical and operating issues** that must be coordinated with the utility are metering, safety, equipment protection, service reliability, and power

quality. IEEE standards address interconnection with the utilities; UL standards apply to inverter and PV module performance and safety; the National Electrical Code governs wiring issues.

- **For situations in which the reliability of grid power is in doubt**, the PV system can be designed to automatically replace it during outages.
- **When planning a utility-interactive system**, be sure to check into metering options, buy and sell rates for power, outdoor disconnect requirements, insurance requirements, and other interconnection costs.



Building-Integrated Photovoltaics systems combine electricity generation with other building envelope functions. A skylight, for example, can both provide daylighting and generate electricity. Spandrel panels in commercial buildings can be power-producing with little, if any, change in appearance. Raised-seam metal roofing and even shingles can serve a dual purpose: shedding rain and generating electricity. BIPV systems often have significant economic advantages over electricity-only PV systems because the BIPV modules are used in place of a building element.

PV SYSTEM DESIGN AND INSTALLATION

PV system design and installation can be complex. This is particularly true for utility-interactive systems and hybrid systems with supplemental power generation. System designers should be familiar with PV and balance-of-system equipment, as well as all applicable codes and regulatory issues. With BIPV systems, architectural expertise is needed to ensure proper integration with the building and satisfaction of building envelope requirements. Hiring experienced, fully qualified PV system designers is key to satisfactory performance, easy maintenance, and long system life.



In 1970, PV cells cost more than \$1,000 per peak watt of power and were used mostly for exotic applications, such as spacecraft power systems. Prices today are under \$4 per peak watt, wholesale, for standard modules. Complete stand-alone systems typically range between \$6 and \$12 per peak watt; BIPV systems range from \$7 to \$15 per peak watt but often earn a credit by replacing conventional building materials.



Source: Craig Miller Productions and DOE

The swimming and diving facility built for the 1996 Summer Olympics uses photovoltaics (front) to produce electricity and a solar-thermal system (back) to heat pool water. Both systems reduce demand on the local utility and result in significant annual energy and cost savings.

STORAGE SYSTEMS

Storage systems for PV arrays make it possible to use captured energy at night or whenever the PV system can't meet the load. A typical storage system is a set of batteries sized to accommodate the PV input as well as the load demand.

When selecting a battery system, the designer needs to consider cyclic and calendar life, daily depth of discharge, temperature and environmental conditions, off-gassing characteristics, size and weight, cost, warranty, availability, reputation of the manufacturer, maintenance requirements, and terminal configuration.

Batteries often contain hazardous materials; the proper use and care of batteries should be a priority throughout their life cycle, including disposal.

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Photovoltaic Fundamentals (DOE/CH10093-117), National Renewable Energy Laboratory, U.S. Department of Energy, revised February 1996.

Photovoltaic System Design Manual (FSC-GP-31-86), Florida Solar Energy Center, Cocoa, FL, revised April 1996.

Contacts

Contact the FEMP Help Desk, (800) DOE-EREC (363-3732), or see the FEMP Web site, www.eren.doe/femp/.

Solar Energy Industries Association, 1616 H Street, NW, 8th Floor, Washington, DC 20006; (202) 628-7745, (202) 628-7779 (fax); www.seia.org.

5.8.6

Wind Energy

Wind energy may be the biggest success story in the arena of alternative or renewable energy systems. Worldwide, wind energy capacity more than tripled over the past 10 years to exceed 10,000 MW by the end of 1999. About 2,500 MW of that capacity is installed in the United States. Over the past 20 years, the cost of producing wind energy has come down from 40 cents per kWh to approximately 3 to 5 cents per kWh for bulk power. The National Renewable Energy Laboratory's National Wind Technology Center (NWTC), located near Boulder, Colorado, supports the research and development of wind energy through a collaborative effort among industry, utilities, environmental groups, and others. NREL researchers predict that near-future design improvements will lower production costs to as little as 2.5 cents per kWh, making wind energy cost-competitive with conventional fuels. Many people are forecasting that wind energy will be the cheapest electricity available from any source within the next 10 to 15 years.

Opportunities

In mid-1999, the U.S. Government made a firm commitment to:

- Use wind power to supply at least 5% of the nation's electricity needs by the year 2020;
- Double the number of states that have more than 20 MW of wind capacity by 2005; and
- Increase to 5% the Federal Government's use of wind-generated electricity by 2010.

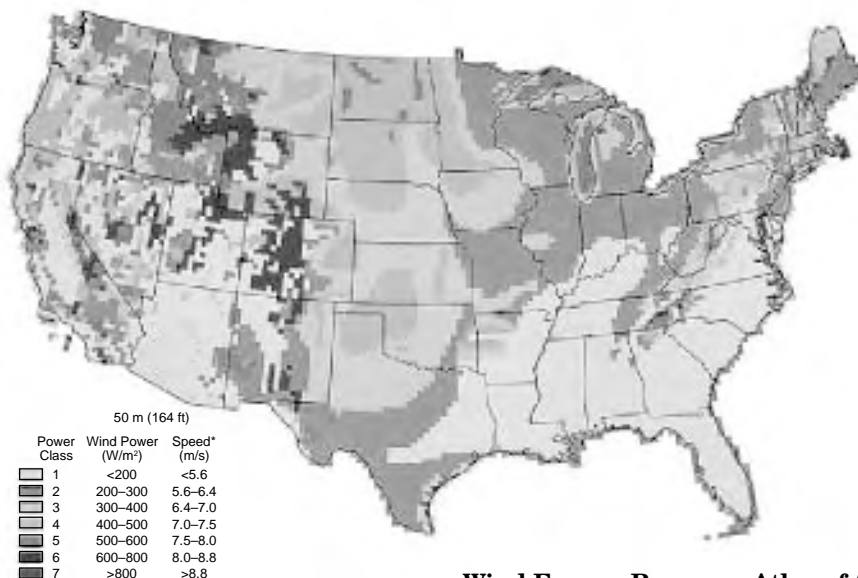
Today's wind turbines are versatile, modular sources of electricity. Small turbines—500 watts to 100 kW—can supply enough electricity to power remote sites, small homes, or business. Large, utility-scale turbines—250 kW and larger—can provide enough electricity to power hundreds of homes and businesses.

Wind energy may be an excellent choice for providing power to facilities if:

- Renewable energy incentives (rebates, tax credits, etc.) are offered;
- The power producer can participate in a production tax credit for renewable energy, established under the Energy Policy Act of 1992;
- Net metering is available in the state or utility district;
- Electricity costs in the area exceed 8 to 12 cents per kWh;
- Diesel or other fossil fuels have to be transported to the site for remote power production;
- The facility is not in compliance with air-pollution regulations; or
- The facility is attempting to meet clean energy goals.

Technical Information

Since earliest recorded history, wind power has been used to move ships, grind grain, and pump water. Today, wind power is also being used to provide electricity to homes, schools, businesses, and entire communities.



*Equivalent wind speed at sea level for a Rayleigh distribution.

Wind Energy Resource Atlas of the United States

Map 2-6: Annual average wind resource estimates in the contiguous United States.

A year of data collection may be necessary to obtain accurate information on wind speeds in a given location or to increase the confidence level in wind data before beginning a project. Equipment to accomplish this can be installed in one day and costs \$1,500 to \$3,000. FEMP also has a CD-ROM containing wind speeds throughout the United States.

This 6-MW wind farm at Searsburg, Vermont, provides emission-free, renewable energy to more than 2,000 households. This installation was funded by the DOE Turbine Development Program. Photo: Green Mountain Power Corp.



More than half the United States has wind resources that could support the development of utility-scale wind power plants, and most states have enough wind to at least support small-scale wind systems. An annual average wind speed in excess of 8 miles per hour (12.9 km/h) is required for small-scale systems to be economical, and annual average wind speeds of at least 11.5 to 12.5 miles per hour (18.5 to 20 km/h) are required for utility-scale turbines.

The power available from wind is proportional to the cube of its speed. At double the wind speed, power generated increases by a factor of 8. Therefore, a wind turbine operating in 11.8 mph (19 km/h) wind can generate 29% more electricity than one operating in 11.2 mph (18 km/h) wind.

Most wind turbines are horizontal-axis machines, with turning blades that resemble propellers. Utility-scale turbines are often grouped together to form a single wind power plant, or *wind farm*, to generate bulk electrical power. Wind turbines are available in a variety of sizes and power ratings. A small home-sized wind machine has blades between 3 and 25 feet (0.9–7.6 m) in diameter and stands upwards of 30 feet (9 m) high. The largest machine stands 20 stories high and has blades that span the length of a football field.

Approximately 50 acres (20 hectares) of land are required per MW for each utility-scale turbine. However, much of the land is actually unoccupied and can be used for farming, ranching, and other activities.

Hybrid wind/diesel systems that combine a wind turbine with a diesel generator provide reliable, economical power. A more sophisticated hybrid system combining wind turbines, photovoltaic (solar electric) panels, and diesel generators provides backup power during low-wind periods, has the ability to supply peak loads under any conditions, and has lower diesel fuel consumption than simpler wind/diesel systems.

Wind energy systems help the U.S. economy by avoiding the external or societal costs associated with conventional energy sources—namely, the trade deficit from importing foreign oil and other fuels, the health and environmental costs of pollution, and the cost of

depleted resources. Wind energy is a reliable domestic resource that provides more jobs per dollar invested than any other conventional power technology—more than five times that from coal or nuclear power. Wind turbine and component manufacturers contribute directly to the economies of most states, creating thousands of jobs for Americans.

A wind energy production tax credit was established under the Energy Policy Act of 1992 as a means of stimulating wind energy development and making wind energy more competitive with conventional energy sources. The tax credit amounts to 1.5 cents per kWh (adjusted for inflation) for electricity produced using wind resources.

It therefore rewards actual electricity generation, rather than equipment installation, and is an important factor in setting the price of long-term wind energy contracts. The credit applies to the first 10 years of production for wind turbines installed between December 31, 1993, and December 31, 2001.

The downsides of wind-turbine-generated electricity include negative visual impacts and occasional bird fatalities. Efforts are being made to mitigate both of these effects. Using turbines of the same size with uniform spacing and analyzing visual impacts with computer simulations can greatly improve the appearance of a wind farm. The National Audubon Society and others are working with the American Wind Energy Association, DOE, and NREL to minimize bird fatalities.

Although wind turbines generate some noise, a 300 kW turbine creates only 45 dB of noise at a distance of about 650 feet (200 m). This noise is usually masked completely by background noise or the natural sound of the wind.

Contacts

American Wind Energy Association, 122 C Street, NW, Suite 380, Washington, DC 20001; (202) 383-2504, (202) 383-2505 (fax); www.awea.org.

National Wind Technology Center, National Renewable Energy Laboratory, 1617 Cole Blvd., Golden, CO 80401; (303) 384-6900; www.nrel.gov/wind/.

Wind Program, Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy; www.eren.doe.gov/wind/.

Wind Powering America, U.S. Department of Energy; www.eren.doe.gov/windpoweringamerica/.

Using biomass as an energy source goes back thousands of years; it was our principal energy source until the 1800s. Biomass is organic matter, such as wood, agricultural crops, and animal waste. In essence, biomass is a form of stored solar energy—produced when plants use energy from the sun to convert air and carbon dioxide into plant tissue through photosynthesis. Energy can be derived from biomass by burning it directly, by converting it into energy-rich gases (gasification) that can fuel advanced gas turbines or fuel cells, and by converting it into liquid fuels (biofuels) that can fuel vehicles and other power-supply equipment. Using combined heat-and-power (cogeneration) systems and the most advanced biomass power-generation equipment, we could achieve total efficiencies of more than 80%.

From an environmental standpoint, biomass energy systems are attractive for several reasons:

- Biomass combustion is climate-neutral, since growing new biomass removes as much (or more) carbon dioxide from the atmosphere as the burning of it releases into the atmosphere.
- The production of certain biomass fuels can reduce pollution risks—for example, the capture of landfill gas (mostly methane) that would contribute to global climate change and the conversion of livestock waste into methane.
- Mixing biomass with coal in coal-fired power plants (co-firing) can reduce polluting emissions.
- Growing perennial biomass fuels instead of cultivated agricultural crops on steep, erosion-prone soils and on buffer strips along waterways can prevent siltation of surface waters and help to prevent runoff of agricultural chemicals and fertilizers.

Opportunities

Biomass energy systems should be considered for facilities with on-site electricity generation, especially when the waste heat from that power generation can be used for industrial processes or district heating (combined heat and power). Biomass energy is most feasible when there is an on-site (or nearby) source, such as waste wood from furniture manufacturing, agricultural crop residues, or a landfill with recoverable methane. Federal facilities can also support biomass energy use through green power purchasing programs in which biomass comprises part of the utility company's power generation mix.

Technical Information

Biomass can be used as an energy source in a number of different ways. These are as follows:

Co-firing: Adding a small percentage of biomass to the fuel supply of a coal-fired power plant—referred to as co-firing—is the easiest short-term option for increasing our use of biomass in power production. Co-firing up to 15% of the fuel mix is currently being done in six U.S. power plants, mostly using wood residues. One coal power plant demonstrated co-firing at 40% biomass substitution for coal. Through co-firing in the nation's coal-fired power plants, which have a combined capacity of 310 gigawatts (GW), biomass could supply 20 to 30 GW by the year 2020, according to the DOE BioPower Program.

Direct combustion of biomass is already widely practiced in certain industries, including lumber mills, furniture and millwork factories, and sugar mills (which produce bagasse as a by-product). In a direct-combustion facility, the biomass is typically burned in a large boiler, producing steam that drives a Rankine-cycle generator. This is much the same process used in coal-fired power plants, though the fuel-handling equipment is different. Most direct-combustion power plants are small (less than 25 MW) and operate at efficiencies of about 20%.

Gasification: Rather than simply burning biomass, a more efficient and cleaner way to extract heat energy from it is through gasification. In this process, biomass is heated in an oxygen-starved environment, which breaks down the biomass into its chemical constitu-



NREL worked with state, community, business, and utility partners to assist in the development of the 50-MW McNeil Generating Station in Burlington, Vermont, which uses wood fuel to produce electricity (cooling towers and excess steam are shown here).

Photo: Dave Parsons

ents and produces *biogas*. This biogas can then be used as fuel in a high-efficiency gas turbine. Sophisticated *gasification combined cycle* (GCC) systems include a gas-turbine topping cycle and a steam-turbine bottoming cycle to achieve efficiencies nearly double those of direct combustion (37% vs. 20%).

Anaerobic digestion: Another way to produce energy from biomass is to anaerobically digest organic matter to generate methane, which can then be burned as fuel. Anaerobic (meaning oxygen-starved) digesters can be used to produce methane from municipal sewage treatment plants, livestock manure tanks, and other nutri-

ent-rich organic matter. In Gronigen, Holland, a biomass digester system has recently been installed that digests the organic component of municipal solid waste to generate 2.5 MW of electricity.

Biofuels: The final approach described for converting biomass into usable energy is to produce liquid fuel from organic matter. Biofuels, as defined by the DOE Biofuels Program, are alcohols, ethers, esters, and other chemicals made from cellulosic biomass. While biofuels can be burned to generate electricity, most of the focus is on biofuels for transportation, especially ethanol and biodiesel. More than 1.5 billion gallons (5.7 billion liters) of ethanol—derived from biomass through a fermentation process—are added to gasoline each year to improve vehicle performance and reduce air pollution. Alcohol is typically used in a 10% blend with gasoline. Biodiesel is an ester that can be made from a variety of vegetable oils and animal fats. Roughly 30 million gallons (113.5 million liters) of U.S. biodiesel are produced annually; most of that is used in a 20% blend with conventional diesel fuel.

References

Numerous documents are available on the BioPower and Biofuels Web sites listed below.

Contacts

Biomass Power Program, National Renewable Energy Laboratory, Golden, CO; www.eren.doe.gov/biopower/.

National Biofuels Program, National Renewable Energy Laboratory, Golden, CO; www.biofuels.nrel.gov.

Combined heat and power, or CHP, is the joint production of both heat (usually steam or hot water) and electricity from a single fuel source. Conventional U.S. power production converts roughly one-third of the Btu from the primary energy source (e.g., coal or natural gas) into electricity; most of the rest is lost as waste heat. Collecting and making productive use of that waste heat can result in total efficiencies over 70%. Combined heat and power is often referred to as *cogeneration*. Many commercial CHP systems go even further, producing electricity, steam, and chilled water from the heat. This is often referred to as *trigeneration*.

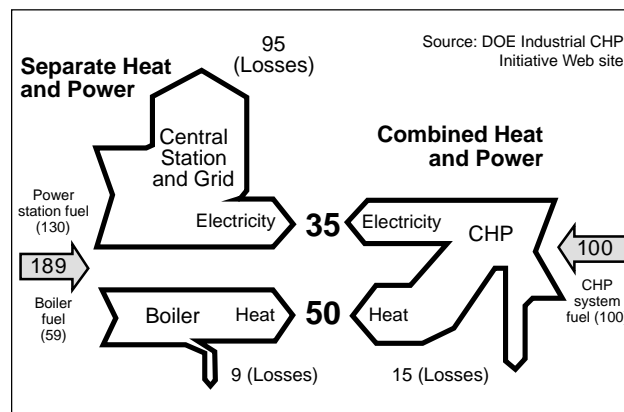
Opportunities

Combined heat and power systems can be implemented on many different levels. At the largest scale, utility power production can be developed in such a way that cogenerated steam is distributed to nearby energy users through a district energy system. Such CHP systems are operating successfully in Boston, Philadelphia, Trenton, St. Louis, and Oklahoma City. In Philadelphia, for example, a CHP plant produces up to 150 MW of electricity while providing steam for 375 district-heating customers that include 70% of the city's downtown commercial buildings and institutional facilities. At the other end of the scale, single buildings can use CHP systems to generate their own electricity while providing thermal energy for internal uses. Between these two extremes, CHP is widely used in industrial facilities that have significant electricity and steam requirements *and* a ready source of fuel—for example, wood products companies and petroleum refineries. CHP systems are also increasingly used at multibuilding institutional facilities, such as universities and hospital complexes.

For single-building applications, CHP systems make the most sense where electric rates and electric demand charges are high. Sometimes opportunities for CHP can be found when the local utility company is looking to bolster its grid through distributed power production or when there is a need for greater reliability than the utility can provide. The best time to consider CHP for a facility is during the initial planning of new buildings and when major upgrades are planned for HVAC systems. Replacing electric chillers with absorption cooling or engine-driven chillers, for example, presents an excellent opportunity for CHP.

Technical Information

Thermal-energy losses from power plants in the U.S. currently total approximately 23 quads (one quad is 10^{15} Btu)—more than one-quarter of total U.S. energy consumption and equal to the total amount of energy spent on transportation.



Combined heat and power is compared with conventional power generation and heat production in this schematic. The total energy inputs required to produce 35 units of electricity and 50 units of heat are indicated for conventional electricity generation, boilers, and a cogeneration system. Cogeneration offers significant energy savings.

For CHP to succeed in buildings, two things are required: (1) an electricity-generation technology that produces excess heat, and (2) a use for the cogenerated heat.

Power-generation technologies that can be used on a small scale in CHP systems include advanced turbine systems, reciprocating spark-ignition (Otto cycle) engines, reciprocating compression-ignition (Diesel cycle) engines, microturbines, and fuel cells.

Practical uses for cogenerated thermal energy in buildings include direct space heating, water heating, absorption chillers, engine-driven chillers, desiccant dehumidification, compressed air, and industrial processes.

Total efficiencies of CHP systems can easily exceed 70%, and efficiencies as high as 90% have been achieved.

Regulatory and market hurdles for CHP include utility interconnection standards, high and often prohibitive utility charges for having backup power available



Photo: Massachusetts Institute of Technology

The air intake for the cogeneration plant at MIT in Cambridge, Massachusetts is pictured above. Waste heat from the gas turbine produces steam for the university.



In the late 1980s, the Massachusetts Institute of Technology (MIT) was spending \$14 million per year on energy—oil and gas for their district-heating steam plant and electricity purchased from the local utility company. Facing rising electricity costs, growth in demand, and a need for more reliable power, MIT decided to install a CHP system. The 22-MW CHP system meets 94% of the university's electricity, heating, and cooling needs. It reduces annual energy costs by 40% and polluting emissions by 45%.

to facilities with on-site power production, unreasonably long depreciation standards for on-site generation, and environmental regulations that do not fairly take into account reductions in polluting emissions that occur beyond the plant being permitted.

Electric industry restructuring (deregulation) is expected to open up new opportunities for CHP by removing barriers that have existed in the current utility system.

The CHP Challenge announced by DOE in 1998 set a goal of doubling by 2010 the amount of U.S. power generated using CHP systems—an increase of 50 GW.

Energy service companies and energy service providers (ESPs) are becoming one-stop providers of heat and power—a trend that is likely to continue. ESCOs and ESPs simplify and reduce the risk of CHP development, particularly for larger projects.

The environmental benefits of meeting the CHP Challenge will include annual reductions of air emissions as follows: 150 million tons of CO₂, one million tons of SO₂, and one-half million tons of NO_x.

References

Combined Heat and Power, Special Supplement to *Energy Matters*, available online at www.oit.doe.gov/bestpractices/.

Elliott, R. Neal, and Mark Spurr, *Combined Heat and Power: Capturing Wasted Energy*, American Council for an Energy-Efficient Economy, Washington, DC, 1999. Executive summary available online, along with other reference materials, at aceee.org/chp/.

Combined Heat and Power: A Vision for the Future of CHP in the U.S. in 2020, U.S. CHP Association, 1999. Available online at www.nemw.org/uschpa/.

Buildings Cooling, Heating, and Power Vision, U.S. Department of Energy, 1999. Available online, along with other reference materials, at www.bchp.org.

Contacts

Office of Power Technologies, U.S. Department of Energy, Washington, DC; (202) 586-6074; www.oit.doe.gov/chpchallenge/ and www.eren.doe.gov/distributedpower/. Numerous fact sheets and reports available, as well as a Web-based software tool to help assess the feasibility of CHP systems for specific applications.

U.S. Combined Heat and Power Association, c/o Northeast-Midwest Institute, 218 D Street, SE, Washington, DC 20003; 202/544-5200; www.nemw.org/uschpa/ (includes links to major corporate stakeholders).

Distributed Power Coalition of America, 10 G Street, NE, Suite 700, Washington, DC 20002; (202) 216-5944; www.dpc.org.

Gas Technology Institute (formerly Gas Research Institute), 8600 W. Bryn Mawr Avenue, Chicago, IL 60631; (773) 399-8100; www.gri.org.