Solution Center

Overview of Potential Energy-Efficiency Measures

Once the key energy problems of a building have been identified through the energy audit, the next task is to select the most cost-effective measure or combination of measures to correct those problems. Certain energy-efficiency measures tend to be implemented more frequently than others since they offer substantial energy savings, rapid paybacks, low costs, and easy implementation. Table 1 lists the most common energy conservation options in four primary building and equipment areas. Although load management is a common retrofit strategy in buildings, it is not always an energy saver and is mostly undertaken to reduce electricity demand and its associated cost.

Table 1: Common Energy-Efficiency Measures in Retrofitted Buildings

Lighting	Mechanical Systems
High-Efficiency Fluorescent Ballasts	Variable-Air-Volume Systems
High Efficiency Fluorescent Fixtures	Air Economizer
High-Efficiency Fluorescent Lamps	High-Efficiency Motors
Programmable Exterior Lighting	Point-of-Use Water Heaters
Task Lighting	Optimized Motor Sizing
PL/SL-Type Fluorescent Lamps	
Metal Halide Lamps	

Shell	Load Management
Vestibules	EMCS Programmable Thermostats
Thermal Break Windows	Curtailable-Load Wiring
Increased Wall Insulation	
Increased Roof Insulation	
Low-Emittance Glazing	

Energy savings opportunities can be found in numerous areas of any building. The areas discussed below include the building shell or envelope, lighting, mechanical systems,district heating and cooling, and operation and maintenance measures.

Building Shell

A building's shell consists of its exterior walls, roof, foundation, doors, windows, skylights, dampers, and other openings. Energy-efficiency improvements to the shell typically include the addition of insulation to walls, floors, attics, and/or ceilings; window upgrades or treatments; and shell "tightening" measures to reduce air infiltration and exfiltration. Shell improvements are most critical for those buildings that have large exterior surface areas relative to their internal volumes. These buildings are primarily "shelldriven," meaning that outdoor conditions are usually the primary determinant of their energy use. Substantially higher energy bills in the winter and summer usually indicate strong weather dependence. Shell insulation is often highly cost effective for these buildings. The lower the level of existing insulation, the more cost effective it will be to add insulation. Where the ratio of shell area to interior volume is small (taller buildings with large interior volumes), internal loads dominate. In such cases, shell improvements have more limited benefits, and those are largely restricted to spaces adjacent to the external skin of the building.

Window treatments (shading, films, screens, etc.) can be very beneficial for buildings with large glass areas facing either south or west. In the summer, especially in southern climates, solar gains through windows can dramatically increase building energy use for cooling. Window treatments to reduce solar gains can pay off rapidly, but this depends on the treatment method used. The installation of more efficient replacement windows is often too expensive an option to pay for itself through avoided energy costs. The exception is buildings

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with large, south- and west-facing glazing areas covering perhaps 50% or more of the wall space. In such buildings, the replacement of clear windows may be cost-justified since large solar gains through windows can account for 25% or more of the cooling load. Recent research, although limited, does show that replacement windows for tall, multifamily buildings can provide substantial energy savings if the existing windows are in poor condition.

Air sealing to minimize air infiltration can also be very cost effective (especially in taller buildings). It is important to find and concentrate air-sealing efforts on the major sources of air leakage into a building, since they can easily account for a large percentage of the air infiltration. Because mechanical ventilation systems for most larger buildings are designed to bring in outdoor air, many buildings operate under a slight positive pressure and, as a result, air leakage into the building is not a concern. If mechanical ventilation is not used, air infiltration will likely be uncontrolled and can result in significantly higher energy use. Where high humidities are present, uncontrolled air infiltration can be an even greater concern because moisture can move through building cavities, where it can be detrimental to the building's structural components and materials.

Smaller commercial buildings sometimes use unconditioned attic space as the return air path to the heating or cooling system. Such routing of return air can lead to substantial air infiltration, since return air plenums are depressurized and will suck in surrounding outside air if not sealed. In these situations, attic surfaces that have connection paths to the outdoors should be sealed (including around all pipes and other penetrations) to prevent unnecessary air infiltration. Some local codes, however, require attics to be ventilated. If this is the case, ensure that connection paths between vents and return air plenums are minimized or, preferably, eliminated. For flat, unventilated roof spaces, the addition of rigid insulation (most cost-effective during a major re-roofing) can help maintain return air temperatures, thus saving energy.

Lighting

There are several important points to remember when working to improve lighting energy efficiency: 1) do not over illuminate; 2) use efficient fixtures, lamps, and ballasts; and 3) control lighting efficiently and keep fixtures and lamps clean. Lighting levels should be tailored to the type of task being performed and the function of the illuminated space. Appropriate lighting power levels for three size ranges of new buildings are presented in Table 2 below. The U.S. Department of Energy (DOE) established these levels as voluntary performance standards (mandatory for Federal buildings) in 1998.

To increase local lighting levels, task lighting should be considered as an alternative to boosting lighting levels across large areas. Lighting levels can be surveyed with inexpensive light meters but the meters must be accurate and they must be used correctly to obtain accurate readings. Lighting levels should be around 50 foot-candles at the work surfaces in offices. In buildings using 4-tube, 2-ballast, fluorescent lighting fixtures, it is not unusual to find that lighting levels are more than twice what is needed –120 foot-candles or more.

Lighting surveys can sometimes enable you to decrease installed capacity by 50%, and since there is little or no capital involved, this measure can pay off rapidly. With the use of efficient lamps and ballasts, adequate office lighting can typically be obtained at an energy level of less than 1 W/ft^2. Lighting energy levels can be estimated in W/ft^2 by summing the rated wattages specified on the installed lamps and ballasts and then dividing by the area of the space. Generally, building spaces with appropriate lighting levels can reduce their fluorescent lighting energy use by around 25 percent with conversion to higher-efficiency lamps and electronic ballasts. In spaces that are highly overlit, 3 W/ft^2 or more, reductions exceeding 60 percent can often be obtained. Different types of lighting are appropriate for different kinds of spaces. The type of lighting used determines achievable efficiencies, color renditioning ability, lamp life, and other important characteristics unique to specific lighting types.

Various methods are available to improve lighting control and performance. Subdividing a lighting system with multiple switches allows minimal lighting use during unoccupied periods or periods of low occupancy. Time clocks, occupancy sensors, and dimming controls are

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also popular methods for reducing lighting energy use. In addition, regular maintenance and cleaning of light fixtures and lamps will increase lighting performance and lamp life.

Lighting energy use is highly dependent on time of use, and therefore, lighting retrofit savings can be more difficult to predict in multifamily buildings than in commercial office buildings. The costs of improvements to lighting energy efficiency are easiest to justify in areas where lighting is used the most. Exterior lighting, corridors and hallways, kitchens, family rooms and other frequently occupied areas are prime candidates.

Table 2: Allowable Lighting Power Densities (W/FT^2)

Building Type	10,000-25,000 ft^2	25,000-50,000 ft^2	50,000-250,000 ft^2
Offices	1.27	1.22	1.16
Service Establishment	1.78	1.65	1.54
Elementary Schools	1.27	1.22	1.16
High Schools	1.39	1.35	1.30
Technical/Vocational	1.60	1.49	1.36
Garages	0.23	0.22	0.20
Warehouses/Storage	0.42	0.36	0.32

(Source: CFR 435, Energy Conservation Voluntary Performance Standards. 1/1/98)

Mechanical Systems

Opportunities for mechanical system retrofits to heating, ventilating, and air conditioning (HVAC) systems are numerous and varied due to the wide assortment of heating and cooling systems and supporting equipment used in buildings. Unlike many lighting retrofits, it can be difficult to determine the energy savings that result from mechanical system retrofits or replacements. Savings are often highly dependent on both the weather and the efficiency of the existing system (which can be challenging to measure). If the efficiency or performance of an existing system can be reliably determined, however, efficiency gains from retrofit or system replacement can often be estimated accurately. If the annual energy use of a mechanical system can be quantified, it can be used with the efficiency change to estimate annual energy savings for a cost analysis. Some of the more popular HVAC retrofits are discussed below.

Common retrofits for maximizing mechanical system efficiencies include 1) operation and maintenance (O&M) improvements; 2) control system improvements; 3) ventilation and distribution system improvements; 4) replacement of existing equipment with higher-efficiency equipment; and 5) improvements to existing equipment.

Operation and Maintenance. O&M resources are the most common retrofits implemented in existing commercial buildings. The Lawrence Berkeley Laboratory has compiled a Building Energy and Compilation Analysis database (known as BECA) that contains information on retrofits of 292 commercial buildings. In these buildings, energy savings average 27percent, and the average payback is 2.2 years. Significantly, 66 percent of these buildings underwent O&M retrofits.

O&M-type retrofits are popular because opportunities are abundant and these measures offer substantial reductions in operating costs, often for very little capital. Some examples of O&M-type retrofits would be periodic maintenance to keep a system operating efficiently; staging of multiple heating or cooling systems to improve part-load performance and minimize operating costs; and the use of manual cutoffs, time clocks, or setback thermostats to reduce run-times.

Control System Improvements. HVAC control system retrofits are also common. In the BECA

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database, HVAC control retrofits were installed in 38 percent of retrofitted commercial buildings. The popularity of these measures is based on their potential for rapid payback, often in less than five years.

Ventilation and Distribution System Improvements. Ventilation retrofits can be major savers or wasters of energy depending on how they are maintained. Economizers are often the most effective. They reduce cooling energy use by bringing in outdoor air when it is sufficient to cool the building interior. The potential energy savings can be substantial because many larger buildings, even in northern climates, operate in a cooling mode year-round due to internal heat gains from people and equipment. In office buildings, cooling energy consumption can be reduced by 10 percent to 50 percent. If economizers fail, however, and go unrepaired, they can be major energy wasters. Depending upon the vent position at the time of failure, they can bring in large amounts of cold, warm, or very humid air during the times of year when it is least desirable. In distribution systems, distributed steam or hot water temperatures are often significantly higher than necessary to support the maximum load on the system, often resulting in excessive air temperatures in some areas of the building. Excessive distribution media temperatures cause increased energy use. In many cases, the temperature of the distribution media can be lowered substantially, yet still meet the maximum load on the system. Since this is a relatively inexpensive measure, rapid paybacks can be obtained. In large hot water distribution systems, opportunities for reducing the volume of pumped water can also save energy. Conversion of constant-air-volume distribution systems to variable-air-volume has attractive paybacks and has also recently increased in popularity.

Equipment Replacement. HVAC equipment at or near the end of its useful life should be considered for replacement with equipment that operates efficiently at both design and part-load operating conditions. For example, most older boilers seldom operate at their rated output. Replacement of such boilers with smaller, high-efficiency, modular (multiple) boilers can boost seasonal efficiencies by 5 percent to 10 percent or more. Replacing existing electric resistance heating systems with heat pumps or other systems that are more efficient or use lower-cost fuel can also provide substantial energy savings.

The replacement of existing cooling equipment with higher-efficiency equipment can also provide attractive paybacks. High-efficiency, direct-expansion cooling units (referred to as packaged or split systems) can be twice as efficient as older systems with standard efficiencies. The energy-efficiency ratio (EER) of the new system divided by that of the old yields an indicator of how much more efficient the new system will be. Higher-efficiency chillers also significantly outperform older systems and meet current U.S. (non-CFC) refrigerant requirements. Chiller coefficients of performance can be compared as an indicator of potential energy efficiency gains.

During the replacement or conversion of a chiller is an opportune time for considering upgrades to all building energy systems related to cooling or affecting cooling load. Installation of efficient chiller systems rather than simple conversion or replacement with units that meet minimum efficiency criteria can be an important energy-saving upgrade.

Reducing cooling loads can enable you to "downsize" your chiller, which will save energy and costs. Cooling loads can be reduced through high-efficiency lighting upgrades, building shell improvements, or other measures. The savings associated with purchasing a smaller chiller may allow a building owner to buy a more efficient model. Savings from lighting or other upgrades could also be used to help offset the extra cost for a more efficient replacement chiller. Another way to reduce new chiller size and cost is to also install new, more efficient HVAC auxiliaries (e.g., evaporative cooling towers, coils, variable-speed drives). Alternatively, you can look for ways to improve the efficiency and operation of auxiliary chiller components, including distribution systems.

Equipment Improvements. As an alternative to replacing existing equipment, there are numerous retrofit options, including O&M measures. For example, capturing rejected heat is a relatively new retrofit approach that is catching on quickly due to attractive energy savings and rapid paybacks. For fossil-fired heating systems, condensing exhaust gases (this captures most of the heat that normally is exhausted through the flue) can recapture heat. Heat recovery from building exhaust air streams is also becoming

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very popular. The recovery is accomplished through heat exchanger coils, heat wheels, and air-to-air heat pipes. In steam systems, the capture of condensate return is essential for efficient operation.

District Heating and Cooling

District heating and cooling (DHC) systems supply energy to about 10 percent of commercial floorspace in this country. Connection to these systems is an option for supplying heating and cooling needs to some buildings. The thermal energy is generated in a central plant and is provided to the consumer through a network of distribution pipes. This eliminates the need in the building for primary heating and cooling equipment, the associated floorspace, and the equipment operators. Up to 50% primary fuel (and air emission) savings can be realized if the DHC thermal energy is produced in an electricity cogeneration plant. The cost of constructing and maintaining a DHC system must be balanced against the cost of owning and operating individual building primary heating and cooling equipment. Because of this, DHC systems tend to be located in high-energy-use, high-density urban areas and multi-building facilities (including educational facilities).

DHC systems offer the advantage of fuel and energy resource flexibility, which can provide greater reliability to customers. Typical costs of heating energy delivered to a building can range from $6-$12 per million Btu. Connection to district cooling systems may be desirable during a building rehabilitation, since the existing CFC chillers must either be replaced or retrofitted in non-CFC refrigerants. Typical connection charge to a central chilled water systems is about $90 per ton cooling capacity, which is about 10 percent of the installed cost of a water chiller. Typical costs of chilled water delivered to a building can range from $12-$25 per million Btu. Central cooling systems are well suited for controlling refrigerant emissions and can cost-effectively produce chilled water using technologies that do not use ozone-depleting refrigerants. DHC systems can also provide a greater reliability by having a diversity of consumer loads, standby central plant equipment, and a full time operating staff. In addition, these systems can help balance the peaks and valleys of electric and thermal demands through the use of thermal storage and non-electric chillers.

A number of measures can be taken to increase the energy efficiency of existing DHC systems. However, it should be remembered that DHC systems are capital intensive, and the energy savings cost reduction must balance against the cost of the measures. Many of the measures could become attractive when the existing system needs repair or expansion.

Changing the existing central energy source to a cogeneration plant leads to fuel and emission savings, as stated above. Thermal losses from the heat distribution network can be reduced by lowering the network operating temperature. Leaks and pipe insulation failure also reduce the efficiency of the distribution network. For steam and hot water systems with temperatures above 250° F, relocating the distribution pipes to dry areas, such as tunnels or shallow trenches, can reduce pipe and insulation failures. Use of hot water systems with temperatures below 250° F has many advantages and should be considered when replacing or expanding an existing system. Staged, variable-speed pumps can greatly reduce electrical energy consumption in hot water and chilled water systems, and they can reduce the chiller energy requirements in chilled water systems.

Planning for connection to an existing or a new DHC system will usually require long lead times, particularly for a new DHC system. There are many stakeholders in this undertaking, including the system developer, the building owner or manager, the governments and their regulatory agencies, the competing utilities, and the financial institutions. All stakeholders must agree on expected capital costs and energy costs to be charged to the users before the system construction actually begins.

Preventive Maintenance

In some cases, the best retrofit measure may be to institute a preventive maintenance program. Any number of situations may make this measure highly cost effective. Systems may have been poorly designed or installed improperly, or building use may have changed over time due to shifts in occupants or alterations to the structure. Building managers and operators are faced with a vast array of designs, computerized technologies, information systems, organizational changes, and management issues. Budgets are frequently too restrictive to allow adequate documentation of procedures or training of staff, particularly in the

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use of computerized control systems and computerized maintenance management tools. The collection and reporting of information about criteria, performance, and results of proper operation and maintenance are often given low priority, and the necessary information never reaches the decision-makers.

For any or all of these reasons, a building may not be operating as efficiently as designed. When the gap between current operations and design is significant, simply bringing a building up to design level may result in significant energy savings. The cost effectiveness of this approach will depend upon the measures required to make the needed improvements (how much they affect energy use and how much they cost).

Integrating Measures

One approach to selecting energy efficiency measures is to consider load-, system-, and plant-level savings opportunities in strict progression. Proponents of this approach cite the multiplier effect that can be achieved if plant-level equipment can be significantly downsized as a result of reduced energy requirements at the load and systems levels. Replacement chillers at the plant level, for example, could be significantly downsized if the building's thermal load and system inefficiencies were reduced. (In commercial buildings, for example, more energy-efficient office equipment could lower the load and simultaneously reduce cooling requirements.) Where capital is limited, however, this approach will not necessarily achieve the greatest energy and cost savings.

Regardless of the particular energy efficiency measures and building upgrades being considered for your stock, it is essential that your team consider the energy use impacts on the entire building. In implementing the upgrade of a single building component, the component is often evaluated upon its own merits, and its impacts on other energy end-use loads are overlooked. This omission can lead to disappointing overall results. The building, its equipment, and occupants are all major determinants of energy use. In addition, they all interact with and can strongly influence one another. Thus, the impact on the building as a "system" must be assessed for any individual or combination of upgrades.

Two examples will serve to illustrate how major interactions can occur between building components. The first example examines potential interactions between lighting improvements and mechanical equipment. Lighting improvements generally lower lighting-generated heat within the building. As a result, cooling energy use will typically decrease and heating energy use will increase. Since overall cost benefits are highly dependent on heating and cooling system efficiencies and fuel costs, dramatic cost benefits might occur in one building, while another building with high heating costs might achieve only half of the predicted savings.

The second example concerns the interaction between mechanical system upgrades and improvements to the building shell. In some cases, upgrading the heating or cooling system while simultaneously adding insulation can dramatically decrease the savings that might have otherwise been gained from the addition of the insulation alone. In this scenario, either measure alone could be cost effective, but the second measure would deliver less benefit per dollar of investment. This illustrates the value of examining overall building energy impacts.

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