CHAPTER 51
ENERGY AUDITING

Carl Blumstein
Universitywide Energy Research Group
University of California
Berkeley, California

Peter Kuhn
Kuhn and Kuhn,
Industrial Energy Consultants
Golden Gate Energy Center
Sausalito, California

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51.1 ENERGY MANAGEMENT AND THE ENERGY AUDIT

Energy auditing is the practice of surveying a facility to identify opportunities for increasing the efficiency of energy use. A facility may be a residence, a commercial building, an industrial plant, or other installation where energy is consumed for any purpose. Energy management is the practice of organizing financial and technical resources and personnel to increase the efficiency with which energy is used in a facility. Energy management typically involves the keeping of records on energy consumption and equipment performance, optimization of operating practices, regular adjustment of equipment, and replacement or modification of inefficient equipment and systems.

Energy auditing is a part of an energy management program. The auditor, usually someone not regularly associated with the facility, reviews operating practices and evaluates energy using equipment in the facility in order to develop recommendations for improvement. An energy audit can be, and often is, undertaken when no formal energy management program exists. In simple facilities, particularly residences, a formal program is impractical and informal procedures are sufficient to alter operating practices and make simple improvements such as the addition of insulation. In more complex facilities, the absence of a formal energy management program is usually a serious deficiency. In such cases a major recommendation of the energy audit will be to establish an energy management program.

There can be great variation in the degree of thoroughness with which an audit is conducted, but the basic procedure is universal. The first step is to collect data with which to determine the facility's major energy uses. These data always include utility bills, nameplate data from the largest energy-using equipment, and operating schedules. The auditor then makes a survey of the facility. Based on the results of this survey, he or she chooses a set of energy conservation measures that could be applied in the facility and estimates their installed cost and the net annual savings that they would

Mechanical Engineers' Handbook, 2nd ed., Edited by Myer Kutz.
ISBN 0-471-13007-9

provide. Finally, the auditor presents his or her results to the facility's management or operators. The audit process can be as simple as a walkthrough visit followed by a verbal report or as complex as a complete analysis of all of a facility's energy using equipment that is documented by a lengthy written report.

The success of an energy audit is ultimately judged by the resulting net financial return (value of energy saved less costs of energy saving measures). Since the auditor is rarely in a position to exercise direct control over operating and maintenance practices or investment decisions, his or her work can come to naught because of the actions or inaction of others. Often the auditor's skills in communication and interpersonal relations are as critical to obtaining a successful outcome from an energy audit as his or her engineering skills. The auditor should stress from the outset of his or her work that energy management requires a sustained effort and that in complex facilities a formal energy management program is usually needed to obtain the best results. Most of the auditor's visits to a facility will be spent in the company of maintenance personnel. These personnel are usually conscientious and can frequently provide much useful information about the workings of a facility. They will also be critical to the success of energy conservation measures that involve changes in operating and maintenance practices. The auditor should treat maintenance personnel with respect and consideration and should avoid the appearance of "knowing it all." The auditor must also often deal with nontechnical managers. These managers are frequently involved in the decision to establish a formal energy management program and in the allocation of capital for energy saving investments. The auditor should make an effort to provide clear explanations of his or her work and recommendations to nontechnical managers and should be careful to avoid the use of engineering jargon when communicating with them.

While the success of an energy audit may depend in some measure on factors outside the auditor's control, a good audit can lead to significant energy savings. Table 51.1 shows the percentage of energy saved as a result of implementing energy audit recommendations in 172 nonresidential buildings. The average savings is more than 20%. The results are especially impressive in light of the fact that most of the energy-saving measures undertaken in these buildings were relatively inexpensive. The median value for the payback on energy-saving investments was in the 1–2 year range (i.e., the value of the energy savings exceeded the costs in 1–2 years). An auditor can feel confident in stating that an energy saving of 20% or more is usually possible in facilities where systematic efforts to conserve energy have not been undertaken.

51.2 PERFORMING AN ENERGY AUDIT—ANALYZING ENERGY USE

A systematic approach to energy auditing requires that an analysis of existing energy-using systems and operating practices be undertaken before efforts are made to identify opportunities for saving energy. In practice, the auditor may shift back and forth from the analysis of existing energy-use patterns to the identification of energy-saving opportunities several times in the course of an audit—first doing the most simple analysis and identifying the most obvious energy-saving opportunities, then performing more complex analyses, and so on. This strategy may be particularly useful if the audit is to be conducted over a period of time that is long enough for some of the early audit recommendations to be implemented. The resultant savings can greatly increase the auditor's credi-

Table 51.1 The Percentage of Energy Saved as a Result of Implementing Energy Audit Recommendations in 172 Nonresidential Buildings[a,4]

	Site		Source	
Building Category	Savings (%)	Sample Size	Savings (%)	Sample Size
Elementary school	24	72	21	72
Secondary school	30	38	28	37
Large office	23	37	21	24
Hospital	21	13	17	10
Community center	56	3	23	18
Hotel	25	4	24	4
Corrections	7	4	5	4
Small office	33	1	30	1
Shopping center	11	1	11	1
Multifamily apartment	44	1	43	1

[a]Electricity is counted at 3413 Btu/kWhr for site energy and 11,500 Btu/kWhr for source energy (i.e., including generation and transmission losses).

bility with the facility's operators and management, so that he or she will receive more assistance in completing his or her work and his or her later recommendations will be attended to more carefully.

The amount of time devoted to analyzing energy use will vary, but, even in a walkthrough audit, the auditor will want to examine records of past energy consumption. These records can be used to compare the performance of a facility with the performance of similar facilities. Examination of the seasonal variation in energy consumption can give an indication of the fractions of a facility's use that are due to space heating and cooling. Records of energy consumption are also useful in determining the efficacy of past efforts to conserve energy.

In a surprising number of facilities the records of energy consumption are incomplete. Often records will be maintained on the costs of energy consumed but not on the quantities. In periods of rapidly escalating prices, it is difficult to evaluate energy performance with such records. Before visiting a facility to make an audit, the auditor should ask that complete records be assembled and, if the records are not on hand, suggest that they be obtained from the facility's suppliers. Good record keeping is an essential part of an energy management program. The records are especially important if changes in operation and maintenance are to be made, since these changes are easily reversed and often require careful monitoring to prevent backsliding.

In analyzing the energy use of a facility, the auditor will want to focus his or her attention on the systems that use the most energy. In industrial facilities these will typically involve production processes such as drying, distillation, or forging. Performing a good audit in an industrial facility requires considerable knowledge about the processes being used. Although some general principles apply across plant types, industrial energy auditing is generally quite specialized. Residential energy auditing is at the other extreme of specialization. Because a single residence uses relatively little energy, highly standardized auditing procedures must be used to keep the cost of performing an audit below the value of potential energy savings. Standardized procedures make it possible for audits to be performed quickly by technicians with relatively limited training.

Commercial buildings lie between these extremes of specialization. The term "commercial building" as used here refers to those nonresidential buildings that are not used for the production of goods and includes office buildings, schools, hospitals, and retail stores. The largest energy-using systems in commercial buildings are usually lighting and HVAC (heating, ventilating, and air conditioning). Refrigeration consumes a large share of the energy used in some facilities (e.g., food stores) and other loads may be important in particular cases (e.g., research equipment in laboratory buildings). Table 51.2 shows the results of a calculation of the amount of energy consumed in a relatively energy-efficient office building for lighting and HVAC in different climates. Office buildings (and other commercial buildings) are quite variable in their design and use. So, while the proportions of energy devoted to various uses shown in Table 51.2 are not unusual, it would be unwise to treat them (or any other proportions) as "typical." Because of the variety and complexity of energy-using systems in commercial buildings and because commercial buildings frequently use quite substantial amounts of energy in their operation, an energy audit in a commercial building often warrants the effort of a highly trained professional. In the remainder of this section commercial buildings will be used to illustrate energy auditing practice.

Lighting systems are often a good starting point for an analysis of energy in commercial buildings. They are the most obvious energy consumers, are usually easily accessible, and can provide good opportunities for energy saving. As a first step the auditor should determine the hours of operation of the lighting systems and the watts per square foot of floorspace that they use. These data, together with the building area, are sufficient to compute the energy consumption for lighting and can be used to compare the building's systems with efficient lighting practice. Next, lighting system maintenance practices should be examined. As shown in Fig. 51.1, the accumulation of dirt on lighting fixtures can significantly reduce light output. Fixtures should be examined for cleanliness and the auditor should determine whether or not a regular cleaning schedule is maintained. As lamps near the end of their rated life, they lose efficiency. Efficiency can be maintained by replacing lamps in groups

Table 51.2 Results of a Calculation of the Amount of Energy Consumed in a Relatively Energy-Efficient Office Building for Lighting and HVAC[5]

	Energy Use ($kBtu/ft^2/yr$)			
	Miami	Los Angeles	Washington	Chicago
Lights	34.0	34.0	34.0	34.0
HVAC auxiliaries	8.5	7.7	8.8	8.8
Cooling	24.4	9.3	10.2	7.6
Heating	0.2	2.9	17.7	28.4
Total	67.1	53.9	70.7	78.8

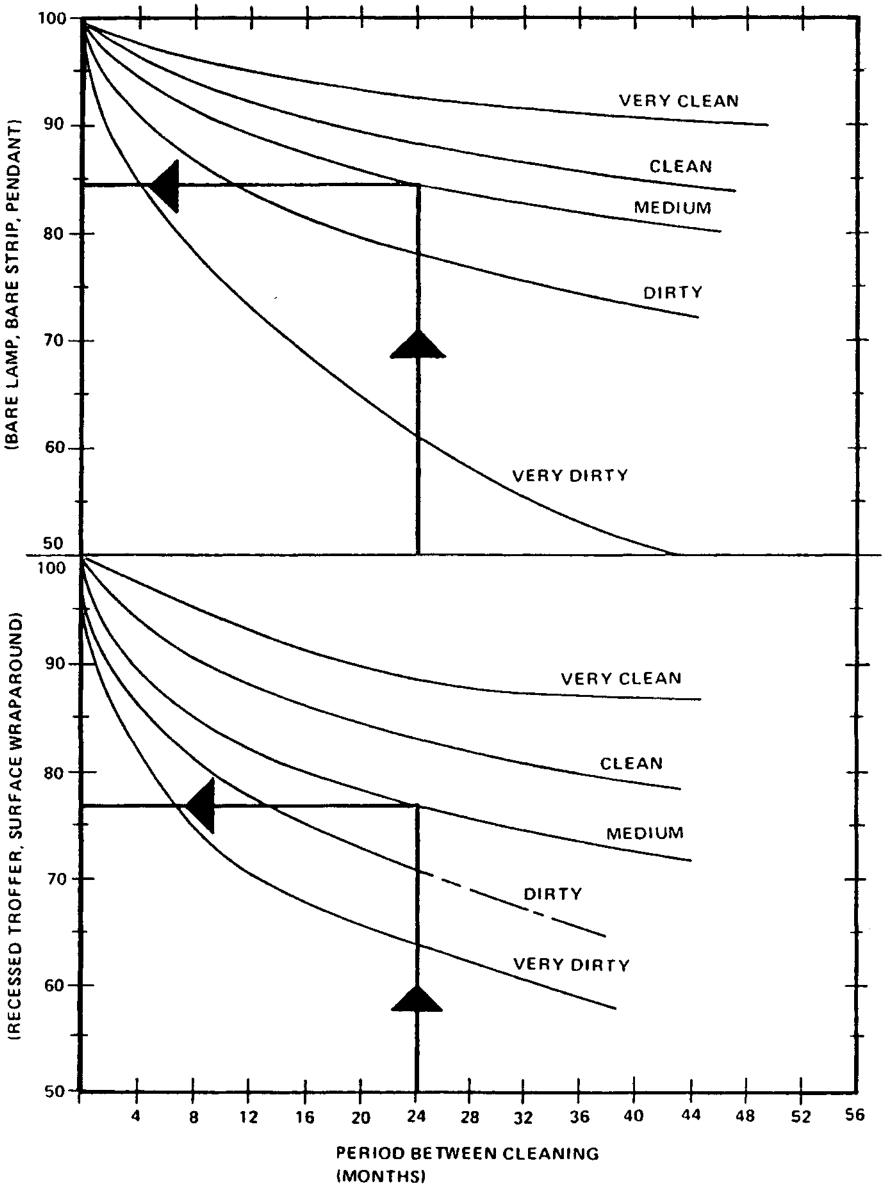

Fig. 51.1 Reduction in light output from fluorescent fixtures as a function of fixture cleaning frequency and the cleanliness of the fixture's surroundings.[3]

before they reach the end of their rated life. This practice also reduces the higher maintenance costs associated with spot relamping. Fixtures should be checked for lamps that are burned out or show signs of excessive wear, and the auditor should determine whether or not a group-relamping program is in effect.

After investigating lighting operation and maintenance practices, the auditor should measure the levels of illumination being provided by the lighting systems. These measurements can be made with a relatively inexpensive photometer. Table 51.3 gives recommended levels of illumination for a variety of activities. A level much in excess of these guidelines usually indicates an opportunity for saving energy. However, the auditor should recognize that good seeing also depends on other factors such as glare and contrast and that the esthetic aspects of lighting systems (i.e., their appearance and the

Table 51.3 Range of Illuminances Appropriate for Various Types of Activities and Weighting Factors for Choosing the Footcandle Level[a] within a Range of Illuminance[6]

Category	Range of Illuminances (Footcandles)	Type of Activity		
A	2–3–5	Public areas with dark surroundings		
B	5–7.5–10	Simple orientation for short temporary visits		
C	10–15–20	Working spaces where visual tasks are only occasionally performed		
D	20–30–50	Performance of visual tasks of high contrast or large size: for example, reading printed material, typed originals, handwriting in ink and good xerography; rough bench and machine work; ordinary inspection; rough assembly		
E	50–75–100	Performance of visual tasks of medium contrast or small size: for example, reading medium-pencil handwriting, poorly printed or reproduced material; medium bench and machine work; difficult inspection; medium assembly		
F	100–150–200	Performance of visual tasks of low contrast or very small size: for example, reading handwriting in hard pencil or very poorly reproduced material; very difficult inspection		
G	200–300–500	Performance of visual tasks of low contrast and very small size over a prolonged period: for example, fine assembly; very difficult inspection; fine bench and machine work		
H	500–750–1000	Performance of very prolonged and exacting visual tasks: for example, the most difficult inspection; extra-fine bench and machine work; extra-fine assembly		
I	1000–1500–2000	Performance of very special visual tasks of extremely low contrast and small size: for example, surgical procedures		
Weighting Factors				
Worker or task charactristics		−1	0	+1
Workers' age		Under 40	40–65	Over 65
Speed and/or accuracy		Not important	Important	Critical
Reflectance of task background		Greater than 70%	30–70%	Less than 30%

[a]To determine a footcandle level within a range of illuminance, find the weighting factor for each worker or task characteristic and sum the weighting factors to obtain a score. If the score is −3 or −2, use the lowest footcandle level; if −1, 0, or 1, use the middle footcandle level; if 2 or 3, use the highest level.

effect they create) can also be important. More information about the design of lighting systems can be found in Ref. 1.

Analysis of HVAC systems in a commercial building is generally more complicated and requires more time and effort than lighting systems. However, the approach is similar in that the auditor will usually begin by examining operating and maintenance practices and then proceed to measure system performance.

Determining the fraction of a building's energy consumption that is devoted to the operation of its HVAC systems can be difficult. The approaches to this problem can be classified as either deterministic or statistical. In the deterministic approaches an effort is made to calculate HVAC energy consumption from engineering principles and data. First, the building's heating and cooling loads are calculated. These depend on the operating schedule and thermostat settings, the climate, heat gains and losses from radiation and conduction, the rate of air exchange, and heat gains from internal sources. Then energy use is calculated by taking account of the efficiency with which the HVAC systems meet these loads. The efficiency of the HVAC systems depends on the efficiency of equipment such as boilers and chillers and losses in distribution through pipes and ducts; equipment efficiency and distribution losses are usually dependent on load. In all but the simplest buildings, the calculation of HVAC energy consumption is sufficiently complex to require the use of computer programs; a number of such programs are available (see, for example, Ref. 2). The auditor will usually make some investigation of all of the factors necessary to calculate HVAC energy consumption. However, the effort involved in obtaining data that are sufficiently accurate and preparing them in suitable form for input to a computer program is quite considerable. For this reason, the deterministic approach is not recommended for energy auditing unless the calculation of savings from energy conservation measures requires detailed information on building heating and cooling loads.

Statistical approaches to the calculation of HVAC energy consumption involve the analysis of records of past energy consumption. In one common statistical method, energy consumption is analyzed as a function of climate. Regression analysis with energy consumption as the dependent variable and some function of outdoor temperature as the independent variable is used to separate "climate-dependent" energy consumption from "base" consumption. The climate-dependent fraction is considered to be the energy consumption for heating and cooling, and the remainder is assumed to be due to other uses. This method can work well in residences and in some small commercial buildings where heating and cooling loads are due primarily to the climate. It does not work as well in large commercial buildings because much of the cooling load in these buildings is due to internal heat gains and because a significant part of the heating load may be for reheat (i.e., air that is precooled to the temperature required for the warmest space in the building may have to be reheated in other spaces). The easiest statistical method to apply, and the one that should probably be attempted first, is to calculate the energy consumption for all other end uses (lighting, domestic hot water, office equipment, etc.) and subtract this from the total consumption; the remainder will be HVAC energy consumption. If different fuel types are used for heating and cooling, it will be easy to separate consumption for these uses; if not, some further analysis of the climate dependence of consumption will be required. Energy consumption for ventilation can be calculated easily if the operating hours and power requirements for the supply and exhaust fans are known.

Whatever approach is to be taken in determining the fraction of energy consumption that is used for HVAC systems, the auditor should begin his or her work on these systems by determining their operating hours and control settings. These can often be changed to save energy with no adverse effects on a building's occupants. Next, maintenance practices should be examined. This examination will usually be initiated by determining whether or not a preventive maintenance (PM) program is being conducted. If there is a PM program, much can be learned about the adequacy of maintenance practices by examining the PM records. Often only a few spot checks of the HVAC systems will be required to verify that the records are consistent with actual practice. If there is no PM program, the auditor will usually find that the HVAC systems are in poor condition and should be prepared to make extensive checks for energy-wasting maintenance problems. Establishment of a PM program as part of the energy management program is a frequent recommendation from an energy audit.

Areas for HVAC maintenance that are important to check include heat exchanger surfaces, fuel-air mixture controls in combustors, steam traps, and temperature controllers. Scale on the water side of boiler tubes and chiller condenser tubes reduces the efficiency of heat transfer. Losses of efficiency can also be caused by the buildup of dirt on finned-tube air-cooled condensers. Improper control of fuel-air mixtures can cause significant losses in combustors. Leaky steam traps are a common cause of energy losses. Figure 51.2 shows the annual rate of heat loss through a leaky trap as a function of the size of the trap orifice and steam pressure. Poorly maintained room thermostats and other controls such as temperature reset controllers can also cause energy waste. While major failures of thermostats can usually be detected as a result of occupant complaints or behavior (e.g., leaving windows open on cold days), drifts in these controls that are too small to cause complaints can still lead to substantial waste. Other controls, especially reset controls, can sometimes fail completely and cause an increase in energy consumption without affecting occupant comfort.

After investigating HVAC operation and maintenance practices, the auditor should make measurements of system performance. Typical measurements will include air temperature in rooms and ducts, water temperatures, air flow rates, pressure drops in air ducts, excess air in stack gases, and current drawn by electric motors operating fans and pumps. Instruments required include a thermometer, a pitot tube or anemometer, a manometer, a strobe light, a combustion test kit, and an ammeter. The importance of making measurements instead of relying on design data cannot be emphasized too strongly. Many, if not most, buildings operate far from their design points. Measurements may point to needed adjustments in temperature settings or air flow rates. Table 51.4 gives recommended air flow rates for various applications. Detailed analysis of the measured data requires a knowledge of HVAC system principles.

After measuring HVAC system performance, the auditor should make rough calculations of the relative importance of the different sources of HVAC system loads. These are primarily radiative and conductive heat gains and losses through the building's exterior surfaces, gains and losses from air exchange, and gains from internal heat sources. Rough calculations are usually sufficient to guide the auditor in selecting conservation measures for consideration. More detailed analyses can await the selection of specific measures.

While lighting and HVAC systems will usually occupy most of the auditor's time in a commercial building, other systems such as domestic hot water may warrant attention. The approach of first

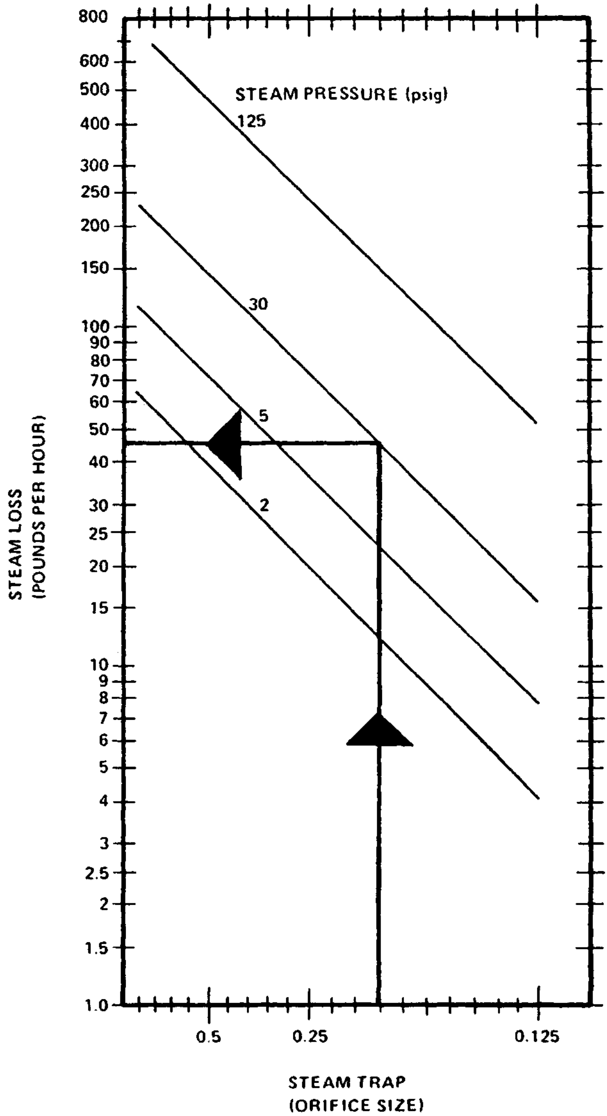

Fig. 51.2 Steam loss through leaking steam traps as a function of stem pressure and trap orifice size.[3]

investigating operation and maintenance practices and then measuring system performance is usually appropriate for these systems.

51.3 PERFORMING AN ENERGY AUDIT—IDENTIFYING OPPORTUNITIES FOR SAVING ENERGY

In almost every facility one can discover a surprisingly large number of opportunities to save energy. These opportunities range from the obvious such as use of light switches to exotic approaches involving advanced energy conversion technologies. Identification of ways to save energy requires imagination and resourcefulness as well as a sound knowledge of engineering principles.

The auditor's job is to find ways to *eliminate unnecessary energy-using tasks* and ways to *minimize the work required to perform necessary tasks.* Some strategies that can be used to eliminate unnecessary tasks are improved controls, "leak plugging," and various system modifications. Taking space conditioning as an example, it is necessary to provide a comfortable interior climate for building

Table 51.4 Recommended Rates of Outside-Air Flow for Various Applications[3]

1. Office Buildings	
Work space	5 cfm/person
Heavy smoking areas	15 cfm/person
Lounges	5 cfm/person
Cafeteria	5 cfm/person
Conference rooms	15 cfm/person
Doctors' offices	5 cfm/person
Toilet rooms	10 air changes/hr
Lobbies	0
Unoccupied spaces	0
2. Retail Stores	
Trade areas	6 cfm/customer
Street level with heavy use (less than 5,000 ft.^{2} with single or double outside door)	0
Unoccupied spaces	0
3. Religious Buildings	
Halls of worship	5 cfm/person
Meeting rooms	10 cfm/person
Unoccupied spaces	0

occupants, but it is usually not necessary to condition a building when it is unoccupied, it is not necessary to heat and cool the outdoors, and it is not necessary to cool air from inside the building if air outside the building is colder. Controls such as time clocks can turn space-conditioning equipment off when a building is unoccupied, heat leaks into or out of a building can be plugged using insulation, and modification of the HVAC system to add an air-conditioner economizer can eliminate the need to cool inside air when outside air is colder.

Chapter 55 of the first edition of this work, "The Exergy Method of Energy Systems Analysis," discusses methods of analyzing the minimum amount of work required to perform tasks. While the theoretical minimum cannot be achieved in practice, analysis from this perspective can reveal inefficient operations and indicate where there may be opportunities for large improvements. Strategies for minimizing the work required to perform necessary tasks include heat recovery, improved efficiency of energy conversion, and various system modifications. Heat recovery strategies range from complex systems to cogenerate electrical and thermal energy to simple heat exchangers that can be used to heat water with waste heat from equipment. Examples of improved conversion efficiency are more efficient motors for converting electrical energy to mechanical work and more efficient light sources for converting electrical energy to light. Some system modifications that can reduce the work required to perform tasks are the replacement of resistance heaters with heat pumps and the replacement of dual duct HVAC systems with variable air volume systems.

There is no certain method for discovering all of the energy-saving opportunities in a facility. The most common approach is to review lists of energy conservation measures that have been applied elsewhere to see if they are applicable at the facility being audited. A number of such lists have been compiled (see, for example, Ref. 3). However, while lists of measures are useful, they cannot substitute for intelligent and creative engineering. The energy auditor's recommendations need to be tailored to the facility, and the best energy conservation measures often involve novel elements.

In the process of identifying energy saving opportunities, the auditor should concentrate first on low-cost conservation measures. The savings potential of these measures should be estimated before more expensive measures are evaluated. Estimates of the savings potential of the more expensive measures can then be made from the reduced level of energy consumption that would result from implementing the low-cost measures. While this seems obvious, there have been numerous occasions on which costly measures have been used but simpler, less expensive alternatives have been ignored.

51.3.1 Low-Cost Conservation

Low-cost conservation measures include turning off energy-using equipment when it is not needed, reducing lighting and HVAC services to recommended levels, rescheduling of electricity-intensive operations to off-peak hours, proper adjustment of equipment controls, and regular equipment maintenance. These measures can be initiated quickly, but their benefits usually depend on a sustained effort. An energy management program that assigns responsibility for maintaining these low-cost measures and monitors their performance is necessary to ensure good results.

In commercial buildings it is often possible to achieve very large energy savings simply by shutting down lighting and HVAC systems during nonworking hours. This can be done manually or, for HVAC systems, by inexpensive time clocks. If time clocks are already installed, they should be maintained in good working order and set properly. During working hours lights should be turned off in unoccupied areas. Frequent switching of lamps does cause some decrease in lamp life, but this decrease is generally not significant in comparison to energy savings. As a rule of thumb, lights should be turned out in a space that will be unoccupied for more than 5 min.

Measurements of light levels, temperatures, and air flow rates taken during the auditor's survey will indicate if lighting or HVAC services exceed recommended levels. Light levels can be decreased by relamping with lower-wattage lamps or by removing lamps from fixtures. In fluorescent fixtures, except for instant-start lamps, ballasts should also be disconnected because they use some energy when the power is on even when the lamps are removed.

If the supply of outside air is found to be excessive, reducing the supply can save heating and cooling energy (but see below on air-conditioner economizers). If possible, the reduction in air supply should be accomplished by reducing fan speed rather than by restricting air flow by the use of dampers, since the former procedure is more energy efficient. Also, too much air flow restriction can cause unstable operation in some fans.

Because most utilities charge more for electricity during their peak demand periods, rescheduling the operation of some equipment can save considerable amounts of money. It is not always easy to reschedule activities to suit the utility's peak demand schedule, since the peak demand occurs when most facilities are engaging in activities requiring electricity. However, a careful examination of major electrical equipment will frequently reveal some opportunities for rescheduling. Examples of activities that have been rescheduled to save electricity costs are firing of electric ceramic kilns, operation of swimming pool pumps, finish grinding at cement plants, and pumping of water from wells to storage tanks.

Proper adjustment of temperature and pressure controls in HVAC distribution systems can cut losses in these systems significantly. Correct temperature settings in air supply ducts can greatly reduce the energy required for reheat. Temperature settings in hot water distribution systems can usually be adjusted to reduce heat loss from the pipes. Temperatures are often set higher than necessary to provide enough heating during the coldest periods; during milder weather, the distribution temperature can be reduced to a lower setting. This can be done manually or automatically using a reset control. Reset controls are generally to be preferred, since they can adjust the temperature continuously. In steam distribution systems, lowering the distribution pressure will reduce heat loss from the flashing of condensate (unless the condensate return system is unvented) and also reduce losses from the surface of the pipes. Figure 51.3 shows the percentage of the heat in steam that is lost due to condensate flashing at various pressures. Raising temperatures in chilled-water distribution systems also saves energy in two ways. Heat gain through pipe surfaces is reduced, and the chiller's efficiency increases due to the higher suction head on the compressor (see Fig. 51.4).

A PM program is needed to ensure that energy-using systems are operating efficiently. Among the activities that should be conducted regularly in such a program are cleaning of heat exchange surfaces, surveillance of steam traps so that leaky traps can be found and repaired, combustion efficiency testing, and cleaning of light fixtures. Control equipment such as thermostats, time clocks, and reset controllers need special attention. This equipment should be checked and adjusted frequently.

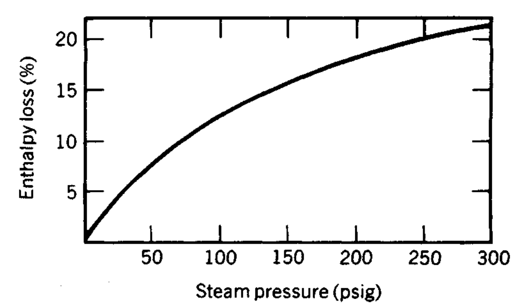

Fig. 51.3 Percentage of heat that is lost due to condensate flashing at various pressures.

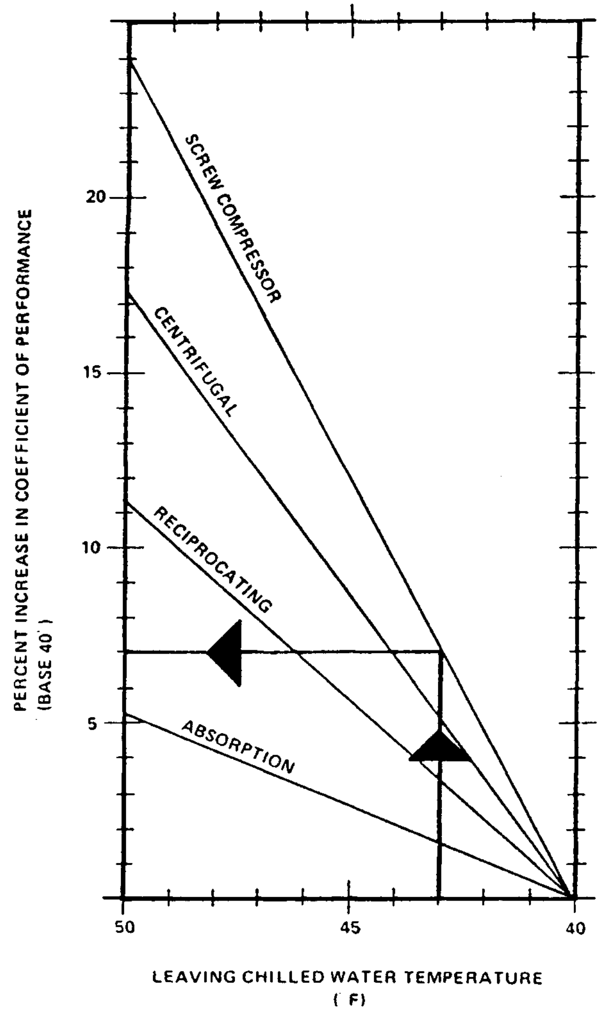

Fig. 51.4 Adjusting air-conditioner controls to provide higher chilled-water temperatures improves chiller efficiency.[3]

51.3.2 Capital-Intensive Energy Conservation Measures

Major additions, modifications, or replacement of energy-using equipment usually require significant amounts of capital. These measures consequently undergo a more detailed scrutiny before a facility's management will decide to proceed with them. While the fundamental approach of eliminating unnecessary tasks and minimizing the work required for necessary tasks is unchanged, the auditor must pay much more attention to the tasks of estimating costs and savings when considering capital-intensive conservation measures.

This subsection will describe only a few of the many possible capital-intensive measures. These measures have been chosen because they illustrate some of the more common approaches to energy saving. However, they are not appropriate in all facilities and they will not encompass the majority of savings in many facilities.

Energy Management Systems

An energy management system (EMS) is a centralized computer control system for building services, especially HVAC. Depending on the complexity of the EMS, it can function as a simple time clock to turn on equipment when necessary, it can automatically cycle the operation of large electrical equipment to reduce peak demand, and it can program HVAC system operation in response to outdoor and indoor temperature trends so that, for example, the "warm-up" heating time before a building is occupied in the morning is minimized. While such a system can be a valuable component of complex building energy service systems, the energy auditor should recognize that the functions of an EMS often duplicate the services of less costly equipment such as time clocks, temperature controls, and manual switches.

Air-Conditioner Economizers

In many areas, outdoor temperatures are lower than return air temperatures during a large part of the cooling season. An air-conditioner economizer uses outside air for cooling during these periods so that the load on the compressor is reduced or eliminated. The economizer is a system of automatic dampers on the return air duct that are controlled by return-air and outside-air temperature sensors. When the outside air is cooler than the return air, the dampers divert the return air to the outdoors and let in enough fresh outside air to supply all the air to the building. In humid climates, economizers must be fitted with "enthalpy" sensors that measure wet-bulb as well as dry-bulb temperature so that the economizer will not let in outside air when it is too humid for use in the building.

Building Exhaust-Air Heat Recovery Units

Exhaust-air heat recovery can be practical for facilities with large outside-air flow rates in relatively extreme climates. Hospitals and other facilities that are required to have once-through ventilation are especially good candidates. Exhaust-air heat recovery units reduce the energy loss in exhaust air by transferring heat between the exhaust air and the fresh air intake.

The common types of units available are heat wheels, surface heat exchangers, and heat-transfer-fluid loops. Heat wheels are revolving arrays of corrugated steel plates or other media. In the heating season, the plates absorb heat in the exhaust air duct, rotate to the intake air duct, and reject heat to the incoming fresh air. Surface heat exchangers are air-to-air heat exchangers. Some of these units are equipped with water sprays on the exhaust air side of the heat exchanger for indirect evaporative cooling. When a facility's exhaust- and fresh-air intakes are physically separated by large distances, heat-transfer-fluid loops (sometimes called run-around systems) are the only practical approach to exhaust-air heat recovery. With the fluid loop, heat exchangers are installed in both the exhaust and intake ducts and the fluid is circulated between the exchangers.

A key factor in estimating savings from exhaust air heat recovery is the unit's effectiveness, expressed as the percentage of the theoretically possible heat transfer that the unit actually achieves. With a 40°F temperature difference between the exhaust and intake air in the heating mode, a 60% effective unit will raise the intake air temperature by 24°F. In units with indirect evaporative cooling, the effectiveness indicates the extent to which the unit can reduce the difference between the intake air dry-bulb temperature and the exhaust air wet-bulb temperature. The effectiveness of commercially available exhaust air heat recovery units ranges from 50% to 80%; greater effectiveness is usually obtained at a higher price per unit of heat recovery capacity.

Refrigeration Heat Recovery

Heat recovery from refrigerators and air conditioners can replace fuel that would otherwise be consumed for low-temperature heating needs. Heat recovery units that generate hot water consist of water storage tanks with an integral refrigerant condenser that supplements or replaces the existing condenser on the refrigerator or air conditioner. These units reduce the facility's fuel or electricity consumption for water heating, and also increase the refrigeration or air conditioning system's efficiency due to the resulting cooler operating temperature of the condenser.

The most efficient condensing temperature will vary, depending on the compressor design and refrigerant, but in most cases it will be below 100°F. In facilities requiring water at higher temperatures, the refrigeration heat recovery unit can preheat water for the existing water heater, which will then heat the water to the final temperature.

Boiler Heat Recovery Devices

Part of the energy conversion losses in a boiler room can be reduced by installing a boiler economizer, air preheater, or a blowdown heat recovery unit. Both the economizer and the air preheater recover heat from the stack gases. The economizer preheats boiler feedwater and the air preheater heats combustion air. The energy savings from these devices are typically 5–10% of the boiler's fuel consumption. The savings depend primarily on the boiler's stack gas temperature. Blowdown heat recovery units are used with continuous blowdown systems and can either supply low-pressure steam to the deaerator or preheat makeup water for the boiler. Their energy savings are typically 1–2% of boiler fuel consumption. The actual savings will depend on the flow rate of the boiler blowdown and the boiler's steam pressure or hot-water temperature.

More Efficient Electric Motors

Replacement of integral-horsepower conventional electric motors with high-efficiency motors will typically yield an efficiency improvement of 2–5% at full load (see Table 51.5). While this saving is relatively small, replacement of fully loaded motors can still be economical for motors that operate

Table 51.5 Comparative Efficiencies and Power Factors (%) for U-Frame, T-Frame, and Energy-Efficient Motors[7]

For Smaller Motors

Horsepower Range: Speed:	3–30 hp 3600 rpm			3–30 hp 1800 rpm			1.5–20 hp 1200 rpm		
Type:	U	T	EEM	U	T	EEM	U	T	EEM
Efficiency									
4/4 load	84.0	84.7	86.9	86.0	86.2	89.2	84.1	82.9	86.1
3/4 load	82.6	84.0	87.4	85.3	85.8	91.1	83.5	82.3	86.1
1/2 load	79.5	81.4	85.9	82.8	83.3	83.3	81.0	79.6	83.7
Power factor									
4/4 load	90.8	90.3	86.6	85.3	83.5	85.8	78.1	77.0	73.7
3/4 load	88.7	87.8	84.1	81.5	79.2	81.9	72.9	70.6	67.3
1/2 load	83.5	81.8	77.3	72.8	70.1	73.7	60.7	59.6	56.7

For Larger Motors

Horsepower Range: Speed:	40–100 hp 3600 rpm			40–100 hp 1800 rpm			25–75 hp 1200 rpm		
Type:	U	T	EEM	U	T	EEM	U	T	EEM
Efficiency									
4/4 load	89.7	89.6	91.6	90.8	90.9	92.9	90.4	90.1	92.1
3/4 load	88.6	89.0	92.1	90.2	90.7	93.2	90.3	90.3	92.8
1/2 load	85.9	87.2	91.3	88.1	89.2	92.5	89.2	89.3	92.7
Power factor									
4/4 load	91.7	91.5	89.1	88.7	87.4	87.6	88.3	88.5	86.0
3/4 load	89.9	89.8	88.8	87.1	85.4	86.3	86.6	86.4	83.8
1/2 load	84.7	85.0	85.2	82.0	79.2	81.1	80.9	80.3	77.8

continuously in areas where electricity costs are high. Motors that are seriously underloaded are better candidates for replacement. The efficiency of conventional motors begins to fall sharply at less than 50% load, and replacement with a smaller high-efficiency motor can yield a quick return. Motors that must run at part load for a significant part of their operating cycle are also good candidates for replacement, since high-efficiency motors typically have better part-load performance than conventional motors.

High-efficiency motors typically run faster than conventional motors with the same speed rating because high-efficiency motors operate with less slip. The installation of a high-efficiency motor to drive a fan or pump may actually increase energy consumption due to the increase in speed, since power consumption for fans and pumps increases as the cube of the speed. The sheaves in the fan or pump drive should be adjusted or changed to avoid this problem.

More Efficient Lighting Systems

Conversion of lighting fixtures to more efficient light sources is often practical when the lights are used for a significant portion of the year. Table 51.6 lists some of the more common conversions and the difference in power consumption. Installation of energy-saving ballasts in fluorescent lights provides a small (5–12%) percentage reduction in fixture power consumption, but the cost can be justified by energy cost savings if the lights are on most of the time. Additional lighting controls such as automatic dimmers can reduce energy consumption by making better use of daylight. Attention should also be given to the efficiency of the luminaire and (for indoor lighting) interior wall surfaces in directing light to the areas where it is needed. Reference 1 provides data for estimating savings from more efficient luminaires and more reflective wall and ceiling surfaces.

51.4 EVALUATING ENERGY CONSERVATION OPPORTUNITIES

The auditor's evaluation of energy conservation opportunities should begin with a careful consideration of the possible effects of energy conservation measures on safety, health, comfort, and productivity within a facility. A conscientious effort should be made to solicit information from knowledgeable personnel and those who have experience with conservation measures in similar facilities. For energy conservation measures that do not interfere with the main business of a facility and the health and safety of its occupants, the determinant of action is the financial merit of a given measure.

Most decisions regarding the implementation of an energy conservation measure are based on the auditor's evaluation of the annual dollar savings and the initial capital cost, if any, associated with

Table 51.6 Some Common Lighting Conversions

Present Fixture				Replacement Fixture			
Type	Power Consumption (W)	Light Output (lumens)	Lifetime (hr)	Type	Power Consumption (W)	Light Output (lumens)	Lifetime (hr)
100-W incandescent	100	1,740	750	8-in. 22-W circline adapter in same fixture	34	980	7,500
500-W incandescent	500	10,600	1,000	175-W metal halide fixture	205	12,000	7,500
Four 40-W rapid-start warm-white 48-in. fluorescent tubes in two-ballast fixture	184	12,800	18,000	Four 34-W energy saver rapid-start tubes in same fixture	160	11,600	18,000
Two 75-W slimline warm-white 96-in. fluorescent tubes in one-ballast fixture	172	12,800	12,000	Two 60-W energy saver slimline tubes in same fixture	142	10,680	12,000
150-W incandescent reflector flood-light (R-40)	150	1,200 (beam candlepower)	5,000	75-W incandescent projector flood-light (PAR-38)	75	1,430 (beam candlepower)	5,000
250-W mercury vapor streetlamp	285	10,400	24,000	150-W high-pressure sodium streetlamp	188	14,400	24,000

the measure. Estimation of the cost and savings from energy conservation measures is thus a critically important part of the analytical work involved in energy auditing.

When an energy conservation opportunity is first identified, the auditor should make a rough estimate of costs and savings in order to assess the value of further investigation. A rough estimate of the installed cost of a measure can often be obtained by consulting a local contractor or vendor who has experience with the type of equipment that the measure would involve. For commercial building energy conservation measures, a good guide to costs can be obtained from one of the annually published building construction cost estimating guides. The most valuable guides provide costs for individual mechanical, electrical, and structural components in a range of sizes or capacities. Rough estimates of the annual dollar savings from a measure can use simplified approaches to estimating energy savings such as assuming that a motor operates at its full nameplate rating for a specified percentage of the time.

If further analysis of a measure is warranted, a more accurate estimate of installed cost can be developed by preparing a clear and complete specification for the measure and obtaining quotations from experienced contractors or vendors. In estimating savings, one should be careful to calculate the measure's effect on energy use using accurate data for operating schedules, temperatures, flow rates, and other parameters. One should also give careful consideration to the measure's effect on maintenance requirements and equipment lifetimes, and include a dollar figure for the change in labor or depreciation costs in the savings estimate.

51.5 PRESENTING THE RESULTS OF AN ENERGY AUDIT

Effective presentation of the energy audit's results is crucial to achieving energy savings. The presentation may be an informal conversation with maintenance personnel, or it may be a formal presentation to management with a detailed financial analysis. In some cases the auditor may also need to make a written application to an outside funding source such as a government agency.

The basic topics that should be covered in most presentations are the following:

1. The facility's historical energy use, in physical and dollar amounts broken down by end use.
2. A review of the existing energy management program (if any) and recommendations for improvement.
3. A description of the energy conservation measures being proposed and the means by which they will save energy.
4. The cost of undertaking the measures and the net benefits the facility will receive each year.
5. Any other effects the measure will have on the facility's operation, such as changes in maintenance requirements or comfort levels.

The auditor should be prepared to address these topics with clear explanations geared to the interests and expertise of the audience. A financial officer, for example, may want considerable detail on cash flow analysis. A maintenance foreman, however, will want information on the equipment's record for reliability under conditions similar to those in his or her facility. Charts, graphs, and pictures may help to explain some topics, but they should be used sparingly to avoid inundating the audience with information that is of secondary importance.

The financial analysis will be the most important part of a presentation that involves recommendations of measures requiring capital expenditures. The complexity of the analysis will vary, depending on the type of presentation, from a simple estimate of the installed cost and annual savings to an internal rate of return or discounted cash flow calculation.

The more complex types of calculations involve assumptions regarding future fuel and electricity price increases, interest rates, and other factors. Because these assumptions are judgmental and may critically affect the results of the analysis, the more complex analyses should not be used in presentations to the exclusion of simpler indices such as simple payback time or after-tax return on investment. These methods do not involve numerous projections about the future.

REFERENCES

1. J. E. Kaufman (ed.), *IES Lighting Handbook,* Illuminating Engineers Society of North America, New York, 1981.
2. M. Lokmanhekim et al., *DOE-2: A New State-of-the-Art Computer Program for the Energy Utilization Analysis of Buildings,* Lawrence Berkeley Laboratory Report, LBL-8974, Berkeley, CA, 1979.
3. U.S. Department of Energy, *Architects and Engineers Guide to Energy Conservation in Existing Buildings,* Federal Energy Management Program Manual, U.S. Department of Energy, Federal Programs Office, Conservation and Solar Energy, NTIS Report DOE/CS-1302, February 1, 1980.
4. L. W. Wall and J. Flaherty, *A Summary Review of Building Energy Use Compilation and Analysis (BECA) Part* C: *Conservation Progress in Retrofitted Commercial Buildings,* Lawrence Berkeley Laboratory Report, LBL-15375, Berkeley, CA, 1982.

5. F. C. Winkelmann and M. Lokmanhekim, *Life-Cycle Cost and Energy-Use Analysis of Sun Control and Daylighting Options in a High-Rise Office Building,* Lawrence Berkeley Laboratory Report, LBL-12298, Berkeley, CA, 1981.
6. California Energy Commission, *Institutional Conservation Program Energy Audit Report: Minimum Energy Audit Guidelines,* California Energy Commission, Publication No. P400-82-022, Sacramento, CA, 1982.
7. W. C. Turner (ed.), *Energy Management Handbook,* Wiley-Interscience, New York, 1982.