Related Commercial Resources

CHAPTER 36

ENERGY USE AND MANAGEMENT

ENERGY management in buildings is the control of energy use and cost while maintaining indoor environmental conditions to provide comfort and to fully meet functional needs. This chapter provides guidance on establishing an effective, ongoing energy management program, as well as information on planning and implementing energy management projects. The energy manager should understand how energy is used in the building, to manage it effectively. There are opportunities for savings by reducing the unit price of purchased energy, and by improving the efficiency and reducing the use of energy-consuming systems.

Water/sewer costs and use may be included in the energy management activity. This could be called "utility management," but "energy management" is used in this chapter.

ENERGY MANAGEMENT

The specific processes by which building owners and operators control energy consumption and costs are as variable as their building types. Small buildings, such as residences and small commercial businesses, usually involve the efforts of one person. Energy management procedures should be as simple, specific, and direct as possible. General energy management advice, such as from utility energy surveys or state or provincial energy offices, can provide ideas, but these must be evaluated to determine whether they are applicable to the target building. Owners and operators of smaller buildings may only need advice on specific energy projects (e.g., boiler replacement, lighting retrofit). On the other hand, large or complex facilities, such as hospital or university campuses, industrial complexes, or large office buildings, usually require a team effort and process as represented in Figure 1.

Figure 1 is adapted from the ENERGY STAR® Web site (www.energystar.gov). On the ENERGY STAR Web site, each box in the flowchart refers the reader to numerous useful tips.

Energy management for existing buildings has these basic steps:

1. Appoint an energy manager to oversee the process and to ensure that someone is dedicated to the initiatives and accountable to the company.
2. Early communication to solicit feedback for other steps of the process.
3. Establish an energy accounting system that records energy and water consumption and associated costs. It should include comparisons with similar buildings, to benchmark and set performance goals.
4. Validate and analyze current and historical energy use data to help identify conservation energy-efficiency measures
5. Carry out energy surveys and walk-through audits to identify low-cost/no-cost operations, maintenance, and energy-efficiency measures. Having a qualified energy professional do this is recommended.

The preparation of this chapter is assigned to TC 7.6, Building Energy Performance.

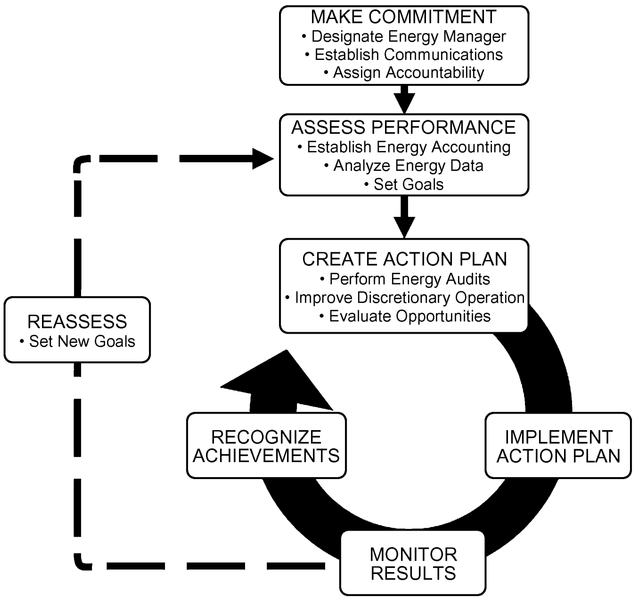


Fig. 1 An Energy Management Process

6. Using the survey results, change building operating procedures to eliminate energy waste.
7. Evaluate energy-efficiency measures for expected savings, estimated implementation costs, risks, and nonenergy benefits. Recommend a number of prioritized energy-efficiency projects for implementation.
8. Implement approved energy-efficiency measures (EEMs). Tender projects that must be outsourced.
9. Track results using the energy accounting system for overall performance, supplemented as needed by energy monitoring related to specific projects.
10. Compare results to past goals, revise as necessary, and develop new goals. Report to management and tenants. Return to step 7 and continue the process to maintain and continually improve building performance.

Each of these energy management program components is discussed in detail in the following sections.

ASHRAE *Standard* 100 gives details useful in energy management planning in existing buildings. Information on energy efficiency in new design can be found in all volumes of the *ASHRAE Handbook* and in ASHRAE *Standards* 90.1 and 90.2. The area most likely to be overlooked in new design is the ability to measure and monitor energy consumption and trends for each energy use category given in Chapter 41. Additional guidelines for this area can be found in Chapter 34 of the 2009 *ASHRAE Handbook—Fundamentals*.

Organizing for Energy Management

To be effective, energy management must be given the same emphasis as management of any other cost/profit center. Top management should

- Establish the energy cost/profit center
- Assign management responsibility for the program
- Assign an energy manager and provide training
- Allocate resources
- Clearly communicate the energy management program to all departments and personnel
- Set clear program goals
- Encourage ownership of the program by all levels of the organization
- Set up an ongoing reporting and analysis procedure to monitor results
- Develop a feedback mechanism to allow timely revisions

It is common for a facility to allocate 3 to 10% of the annual energy cost for administration of an energy management program. The budget should include funds for continuing education of the energy manager and staff.

Energy Managers

The functions of an energy manager fall into four broad categories: technical, policy-related, planning and purchasing, and public relations. A list of specific tasks and a plan for their implementation must be clearly documented and communicated to building occupants. An energy manager in a large commercial complex may perform most of the following functions; one in a smaller facility may have only a few from each category to consider.

Technical functions

- Conduct energy audits and identifying energy-efficiency measures
- Act as in-house technical consultant on new energy technologies, alternative fuel sources, and energy-efficient practices
- Evaluate energy efficiency of proposed new construction, building expansion, remodeling, and new equipment purchases
- Set performance standards for efficient operation and maintenance of equipment and facilities
- Review state-of-the-art energy management hardware
- Review building operation and maintenance procedures for optimal energy management
- Implement energy-efficiency measures (EEMs)
- Establish an energy accounting system
- Establish a baseline from which energy-saving improvements can be measured
- Measure and maintain effectiveness of EEMs
- Measure energy use in the field to verify design and operating conditions

Policy-related functions

- Fulfill energy policy established by top management
- Monitor federal and state (provincial) legislation and regulatory activities, and recommend policy/response
- Adhere to energy management building codes
- Represent the organization in energy associations
- Administer government-mandated reporting programs

Planning and purchasing functions

- Take advantage of fuel-switching and load management opportunities
- Purchase equipment based on life-cycle cost
- Take advantage of energy-efficiency programs offered by utilities and agencies
- Negotiate or advise on major utility contracts
- Develop contingency plans for supply interruptions or shortages
- Forecast and budget for short- and long-term energy requirements and costs
- Report regularly to top management and other stakeholders.

Public relations functions

- Make occupants aware of the benefits of efficient energy use
- Establish a mechanism to elicit and evaluate suggestions
- Recognize successful energy projects
- Establish an energy communications network
- Increase community awareness with press releases and appearances at civic group meetings

General qualifications

- A technical background, preferably in engineering
- Experience in energy-efficient design of building systems and processes
- Practical, hands-on experience with systems and equipment
- Goal-oriented management style
- Ability to work with people at all levels
- Technical report-writing and verbal communication skills

Desirable educational and professional qualifications

- Bachelor of science degree, preferably in mechanical, electrical, industrial, or chemical engineering
- Thorough knowledge of energy resource planning and conservation
- Ability to
  - Analyze and compile technical and statistical information and reports
  - Interpret plans and specifications for building facilities
- Knowledge of
  - Utility rates, energy efficiency, and planning
  - Automatic controls and systems instrumentation
  - Energy-related metering equipment and practices
  - Project management

If it is not possible to add a full-time manager, an existing employee with a technical background should be considered and trained. Energy management should not be a collateral duty of an employee who is already fully occupied. Another option is to hire a professional energy management consultant. Energy services companies (ESCOs) provide energy services as part of a contract, with payments based on realized savings. Other companies charge a fee to perform a variety of energy management functions.

COMMUNICATIONS

Energy management requires careful planning and help from all personnel that operate and use the facility. A communication plan should be regularly reviewed by both the energy manager and senior management. The initial communiqué should introduce the plan and express the support of top management for high-level goals. Providing early information to tenants and staff is important, because it takes time to change behaviors. Once the communication plan is launched, the energy manager should be prepared to answer a variety of questions from different areas of the company.

An effective communication strategy may include these tasks:

- Produce a regular newsletter
- Post energy-saving tips or reminders
- Hold annual seminars with maintenance and cleaning staff
- Meet with operations staff for training and feedback
- Report regularly to management and operations staff

Message content should be tailored to the specific audience. The more successful the communication is, the more quickly the energy management activities will become second nature. Diligent reporting promotes accountability and persistence of performance.

ENERGY ACCOUNTING SYSTEMS

An energy accounting system that tracks consumption and costs on a continuing basis is essential. It provides energy use data needed to confirm savings from energy-efficiency projects. The primary data source is utility bills, but other sources include

- Printouts from time-of-use meters
- Combustion efficiency, eddy current, and water quality tests
- Recordings of temperature and relative humidity
- Submetered energy use
- Event recordings
- Occupancy schedules and occupant activity levels
- Climate data
- Data from similar buildings in similar climates
- Infrared scans
- Production records
- Computer modeling

Energy Accounting Process

The energy manager establishes procedures for meter reading, monitoring, and tabulating facility energy use and profiles. The energy manager also periodically reviews utility rates, rate structures, and trends, and should subscribe to free utility mailing lists to track changes in their rate tariffs. The energy manager provides periodic reports to top management, summarizing the work accomplished, its cost-effectiveness, plans for future work, and projections of utility costs. Utility bill analysis software can be used to track avoided costs. If energy-efficiency measures are to be cost-effective, continued monitoring and periodic reauditing are necessary to ensure persistence. The procedures in ASHRAE *Guideline* 14 can be used for measurement and verification of energy savings.

Energy Accounting

Energy accounting means tracking utility bill data on a monthly basis to provide a current picture of building energy performance and to identify trends and instances of excess use. An Internet search for "energy accounting" will produce Web sites for the major commercial providers. In some cases software is sold for computer installation, or the accounting system is web-based and the user has a subscription. For many users, a simple spreadsheet is all that is needed. A comparison of the features of many available energy accounting software packages can be found at http://www.betterbricks.com/DetailPage.aspx?ID=518. Portfolio Manager, from the ENERGY STAR Web site, allows users to enter monthly energy usage, in kWh, therms, etc. The Portfolio Manager simultaneously calculates the facility's EUI and develops a normalized ENERGY STAR score (http://www.energystar.gov/benchmark). Portfolio Manager facilitates comparison of multiple buildings and goal setting, is useful for numerous building types, and is normalized by building type for weather.

Utility Rates

Because most energy management activities are dictated by economics, the energy manager must understand the utility rates that apply to each facility. Electric rates are more complex than gas or water rates and some rate structures make cost calculations difficult. In addition to general commercial or institutional electric rates, special rates may exist such as time of day, interruptible service, on peak/off peak, summer/winter, and peak demand. Electric rate schedules vary widely in North America; Chapters 37 and 56 discuss these in detail. Energy managers should work with local utility companies to identify the most favorable rates for their buildings, and must understand how demand is computed as well as the distinction between marginal and average costs (see the section on Improving Discretionary Operations). The utility representative can help develop the most cost-effective methods of metering and billing.

ANALYZING ENERGY DATA

Preparing for Cost and Efficiency Improvements

Opportunities for savings come in reducing (1) the cost per unit of energy, and then (2) energy consumption. Historically, energy users had little choice in selecting energy suppliers, and regulated tariffs applied based on certain customer characteristics. In recent years there has been a move in North America and other parts of the world to deregulate energy markets. and there is more flexibility in supply and pricing. Electric rate structures vary widely in North America; Chapter 37 discusses these in detail.

Electric utilities commonly meter both consumption and demand. **Demand** is the peak rate of consumption, typically averaged over a 15 or 30 min period. Electric utilities may also use a ratchet billing procedure for demand. Contact the local electric utility to fully understand the demand component.

Some utilities use **real-time pricing (RTP)**, in which the utility calculates the marginal cost of power per hour for the next day, determines the price, and sends this hourly price to customers. The customer can then determine the power consumption at different times of the day. A variation on RTP was introduced in some areas: **demand exchange and active load management** pays customers to shed loads during periods of high utility demand. Also called **demand reduction** or **demand response**, the utilities ask participating customers to reduce their consumption for a period of time on as little as a few hours' notice.

Caution is advised in designing or installing systems that take advantage of utility rate provisions, because the structure or provisions of utility rates cannot be guaranteed for the life of the system. Provisions that change include on-peak times, declining block rates, and demand ratchets. Chapter 56 has additional information on billing rates.

Analyzing Energy Use Data

Any reliable utility data should be examined. Utilities often provide metered data with measurement intervals as short as 15 min. Data from shorter time intervals make anomalies more apparent. High consumption at certain periods may reveal opportunities for cost reduction (Haberl and Komor 1990a, 1990b). If monthly data are used, they should be analyzed over several years.

A base year should be established as a reference point. Record the dates of meter readings so that energy use can be normalized for the number of days in a billing period. Any periods in which consumption was estimated rather than measured should be noted.

If energy data are available for more than one building or department, each should be tabulated separately. Initial tabulations should include both energy and cost per unit area (in an industrial facility, this may be energy and cost per unit of goods produced). Document variables such as heating or cooling degree-days, percent occupancy, quantity of goods produced, building occupancy, hours of operation, or daily weather conditions (see Chapter 14, Climatic Design Information, in the 2009 *ASHRAE Handbook—Fundamentals*). Because these variables may not be directly proportional to energy use, it is best to plot information separately or to superimpose one plot over another. Examples of ways to normalize energy consumption for temperature and other variations are provided in ASHRAE *Guideline* 14.

Potential savings areas can be identified by separating base energy consumption from weather-dependent energy consumption. **Base-load energy use** is the amount of energy consumed independent of weather, such as for lighting, motors, domestic hot water, and miscellaneous office equipment. When a building has electric cooling and no electric heating, the base-load electric energy use is normally the energy consumed during the winter. The annual base-load energy use may also be estimated by taking the average monthly use during nonheating or noncooling months and multiplying by 12. For many buildings, subtracting the base-load energy use

Table 1 Electricity Consumption for Atlanta Example Building

Year	Month	Bill Start	Bill End	Billing Period	Billed Use, kWh	Actual Demand, kW	Billed Demand, kW	LF	Daily Use, kWh	Daily Base Use, kWh	Monthly Base Use, kWh	Percent Excess Use, kWh
		Occupancy Factor		32.7%			Building Area: 30,700 ft^2					
		Summer ELF 2002		82.5%	Summer ELF 2003		37.4%	Summer ELF 2004		54.7%		
2002	Jan-02	1/2/2002	1/31/2002	29	54,600	166	166	47.3%	1883	1665	48,285	11.6%
2002	Feb-02	1/31/2002	2/28/2002	28	46,620	148	166	46.9%	1665[a]	1665	46,620	0.0%
2002	Mar-02	2/28/2002	4/1/2002	32	60,900	140[b,c]	166	56.6%	1903	1665	53,280	12.5%
2002	Apr-02	4/1/2002	4/29/2002	28	56,340	166	166	50.5%	2012	1665	46,620	17.3%
2002	May-02	4/29/2002	5/31/2002	32	65,520	159	166	53.7%	2048	1665	53,280	18.7%
2002	Jun-02	5/31/2002	6/28/2002	28	63,540	180	180	52.5%	2269	1665	46,620	26.6%
2002	Jul-02	6/28/2002	7/31/2002	33	76,860	158	171	61.4%	2329	1665	54,945	28.5%
2002	Aug-02	7/31/2002	8/30/2002	30	82,620	192	192	59.8%	2754[a]	1665	49,950	39.5%
2002	Sep-02	8/30/2002	9/30/2002	31	66,780	195[b]	195[b]	46.0%	2154	1665	51,615	22.7%
2002	Oct-02	9/30/2002	10/29/2002	29	60,720	193	185	45.2%	2094	1665	48,285	20.5%
2002	Nov-02	10/29/2002	12/2/2002	34	62,100	151	185	50.4%	1826	1665	56,610	8.8%
2002	Dec-02	12/2/2002	1/2/2003	31	60,180	166	185	48.7%	1941	1665	51,615	14.2%
2003	Jan-03	1/2/2003	1/31/2003	29	57,120	178	185	46.1%	1970	1704	49,429	13.5%
2003	Feb-03	1/31/2003	3/3/2003	31	61,920	145	185	57.4%	1997	1704	52,838	14.7%
2003	Mar-03	3/3/2003	4/1/2003	29	60,060	140	185	61.6%	2071	1704	49,429	17.7%
2003	Apr-03	4/1/2003	4/30/2003	29	62,640	154	185	58.4%	2160	1704	49,429	21.1%
2003	May-03	4/30/2003	6/2/2003	33	73,440	161	185	57.6%	2225[a]	1704	56,247	23.4%
2003	Jun-03	6/2/2003	6/28/2003	26	53,100	171	185	49.8%	2042	1704	44,316	16.5%
2003	Jul-03	6/28/2003	7/30/2003	32	67,320	180[b]	185[b]	48.7%	2104	1704	54,542	19.0%
2003	Aug-03	7/30/2003	8/29/2003	30	66,000	170	185	53.9%	2200	1704	51,133	22.5%
2003	Sep-03	8/29/2003	9/30/2003	32	63,960	149	171	55.9%	1999	1704	54,542	14.7%
2003	Oct-03	9/30/2003	10/30/2003	30	55,260	122	171	62.9%	1842	1704	51,133	7.5%
2003	Nov-03	10/30/2003	11/26/2003	27	46,020	140	171	50.7%	1704[a]	1704	46,020	0.0%
2003	Dec-03	11/26/2003	12/30/2003	34	61,260	141	171	53.2%	1802	1704	57,951	5.4%
2004	Jan-04	12/30/2003	1/30/2004	31	59,040	145	171	54.7%	1905	1676	51,960	12.0%
2004	Feb-04	1/30/2004	2/28/2004	29	54,240	159	171	49.0%	1870	1676	48,608	10.4%
2004	Mar-04	2/28/2004	3/19/2004	20	37,080	122	171	63.3%	1854	1676	33,523	9.6%
2004	Apr-04	3/19/2004	3/31/2004	12	22,140	133	171	57.8%	1845	1676	20,114	9.2%
2004	May-04	3/31/2004	5/4/2004	34	64,260	148	171	53.2%	1890	1676	56,988	11.3%
2004	Jun-04	5/4/2004	6/2/2004	29	63,720	148	171	61.9%	2197	1676	48,608	23.7%
2004	Jul-04	6/2/2004	7/2/2004	30	69,120	169	169	56.8%	2304	1676	50,284	27.3%
2004	Aug-04	7/2/2004	8/3/2004	32	73,800	170[b]	170[b]	56.5%	2306[a]	1676	53,636	27.3%
2004	Sep-04	8/3/2004	9/1/2004	29	64,500	166[b]	166[b]	55.8%	2224	1676	48,608	24.6%
2004	Oct-04	9/1/2004	10/1/2004	30	60,060	152	161	54.9%	2002	1676	50,284	16.3%
2004	Nov-04	10/1/2004	11/2/2004	32	65,760	128	161	66.9%	2055	1676	53,636	18.4%
2004	Dec-04	11/2/2004	12/3/2004	31	51,960	132	161	52.9%	1676[a]	1676	51,960	0.0%

	kWh·y/ft^2	Days	Total kWh	Peak kW	Billed kW	Avg LF	Daily Base Use, kWh	Total Base Use, kWh
2002	24.65	365	756,780	195	195	51.6%	1665	607,725
2003	23.72	362	728,100	180	185	51.5%	1704	617,009
2004	22.33	339	685,680	170	171	52.4%	1676	568,208

[a]Maximum or minimum value for year. [b]Peak demand for year. [c]Minimum demand used in seasonal ELF calculation.

from total annual energy use yields a good estimate of heating or cooling energy consumption. This approach is not valid when building operation differs from summer to winter, when cooling operates year-round, or when space heating is used during summer (e.g., for reheat). Base-load analysis can be improved by using hourly load data. **Electric load factors (ELFs)** and occupancy factors can also be used instead of hourly energy profiles (Haberl and Komor 1990a, 1990b).

Although it can be difficult to relate heating and cooling energy directly to weather, several authors, including Fels (1986) and Spielvogel (1984), suggest that this is possible using a curve-fitting method to calculate the balance point of a building (discussed in Chapter 19 of the 2009 *ASHRAE Handbook—Fundamentals*). For this method, building use must be regular, and actual rather than estimated data must be used, along with accurate dates and weather data.

More detailed breakdown of energy use requires that some metered data be collected daily (winter versus summer days, weekdays versus weekends) and that some hourly information be collected to develop profiles for night (unoccupied), morning warm-up, day (occupied), and shutdown. Submetering of energy end uses is recommended for optimal energy management. For more information, see Chapter 41.

An example spreadsheet using three years of electricity bill data for a two-story office building in Atlanta, Georgia, is presented in Table 1. (See Chapter 18 of the 2009 *ASHRAE Handbook—Fundamentals* for floor plans and elevations of the building.)

Electrical Use Profile

The **electrical use profile (EUP)** report, shown in Figure 2, divides electrical consumption into base and weather-dependent consumption. The average daily consumption for each month appears in the daily use column in Table 1, and is plotted in the EUP

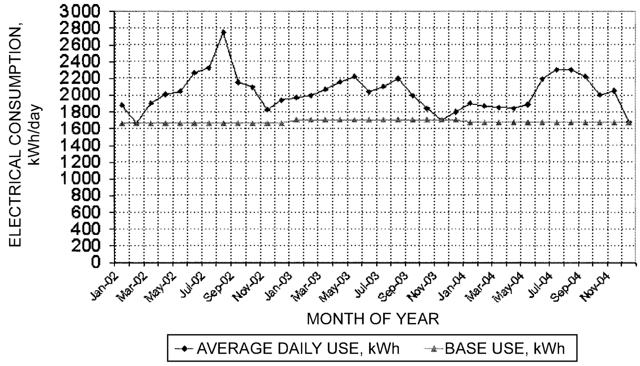


Fig. 2 Electrical Use Profile for Atlanta Example Building

graph. The average daily consumption is calculated by dividing the consumption for a particular month by its billing days.

The lowest value in the daily-use column is used to plot the facility's base electrical consumption (shown as the base use line) in Figure 2. Where a facility uses electricity only for cooling or heating, or in an all-electric facility where there is no overlap between cooling and heating, the difference between these two lines represents the weather-dependent electrical consumption.

Weather-dependent energy consumption (either electric or other fuels) may then be compared to the **cooling degree-days (CDD)** or **heating degree-days (HDD)** totals for the same time period (see Chapter 14 of the 2009 *ASHRAE Handbook—Fundamentals*). This comparison shows how the building performs from month to month or year to year. The HDDs stop and CDDs start at the balance point, defined as the outdoor temperature at which, for a specified interior temperature, the total heat loss is equal to the heat gain from the sun, occupants, lights, etc. Note that all-electric buildings may have periods of overlap between heating and cooling, causing the base load to be overestimated and the heating and cooling estimates to be conservative.

Examine the average daily use line to see whether it follows the expected seasonal curve. For example, the shoulders of the curve for an electrically cooled, gas-heated hospital should closely follow the base electrical use line in the winter. As summer approaches, this curve should rise steadily to reflect the increased cooling load. Errors in meter readings, reading dates, or consumption variances appear as unusual peaks or valleys. Reexamine the data and correct errors as necessary.

If an unusual profile remains after correcting any errors, an area of potential energy savings may exist. For example, if the average daily use line for the facility is running near summer levels during March, April, May, October, and November, simultaneous heating and cooling may be occurring. This situation is illustrated in Figure 2, and often occurs with dual-duct systems.

Simultaneous heating and cooling is also indicated in the percent excess use column of Table 1. The values show the percent difference between the value appearing in the monthly base use column and the billed consumption for the month. In Figure 2, note how the excess consumption for spring and fall months runs close to the summer percentages. The monthly base use is the lowest value from the daily use column multiplied by the number of billing days for each month.

For electrically cooled, gas-heated facilities, weather-dependent consumption is the difference between the totals of the monthly base use column and the billed use column.

For an all-electric facility, subtract the total monthly consumption from total billed use for the cooling months, then do the same calculations for heating months to determine the electric cooling and heating loads, respectively.

Calculating Electrical Load and Occupancy Factors

Another method for detecting potential energy savings is to compare the facility's electrical load factor to its occupancy factor. An ELF exceeding its occupancy factor indicates a higher-than-expected electric use occurring outside normal occupancy (e.g., lights or fans are left on or air conditioning is not shut off as early in the day as possible in summer). Setback thermostats, direct digital control (DDC) strategies, time-of-day scheduling, and lighting controls can address this.

The ELF is the ratio between the average daily use and the maximum possible use if peak demand operated for a 24 h period. The occupancy factor is the ratio between the hours a building actually is occupied and 24 h/day occupancy.

To calculate the ELF, find the month with the lowest demand on the utility data analysis spreadsheet. This value represents the base monthly peak demand, and is usually found in the same or adjacent month as the month with the lowest consumption. From the EUP report, find the lowest value in the daily use column. For example, the lowest average daily use for the office building in Table 1 is 1704 kWh (in November 2003), and the lowest monthly demand from the spreadsheet is 122 kW (in October 2003). The ELF is calculated as follows:

$$\text{ELF} = \frac{\text{Lowest average daily use}}{\text{Lowest monthly demand} \times 24} = \frac{1704}{122 \times 24} = 58\%$$

The office is normally occupied from 7:30 AM to 6:30 PM, Monday to Friday. Therefore, the occupancy factor is calculated as

$$\text{Occupancy factor} = \frac{\text{Actual weekly occupied hours}}{24\ \text{h} \times 7\ \text{days}} = \frac{55}{168} = 33\%$$

Calculating Seasonal ELFs

ELFs can also be calculated for cooling and heating seasons. Typical defaults are May to August as cooling months, and the rest of the year as heating months, but these change based on climate.

The steps for calculating a seasonal ELF are as follows:

1. The daily base consumption is determined from the daily use column of the EUP report. Subtract the lowest value of the year from the highest value of the season.
2. The base demand is determined by subtracting the lowest monthly demand for the year from the demand recorded for the month with the highest daily use. These calculations can be refined further if on- and off-peak data are available.

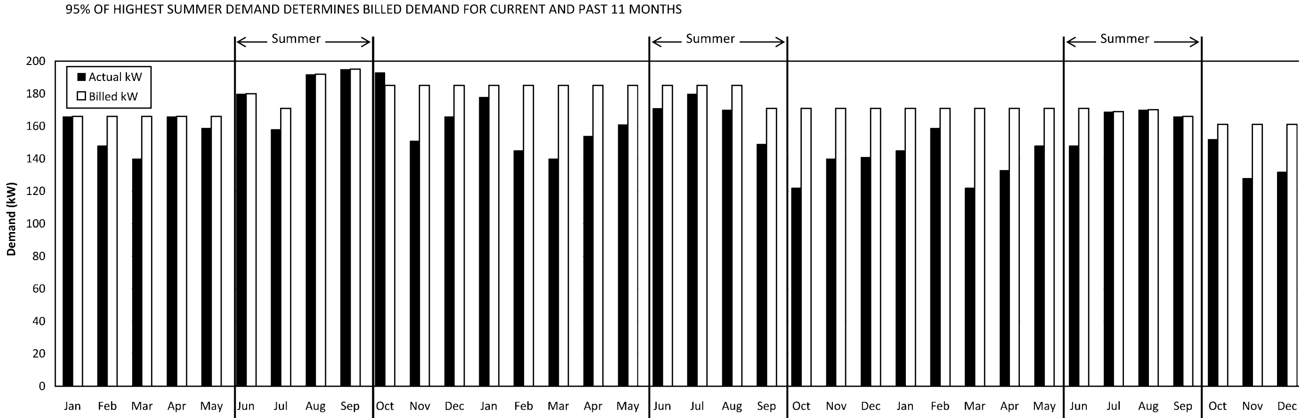
For example, because the electrically cooled Atlanta example building operates year-round, the summer ELF must also be calculated. The daily base consumption (1089) is determined from subtracting the lowest value (1665) from the highest cooling-season value (2754) in the daily use column of the EUP report.

From the spreadsheet, take the demand from September 2002 (the month with the peak cooling-season actual demand) and subtract the lowest monthly demand from the spreadsheet (195 – 140) to determine the cooling-season base demand (55). Thus, the summer ELF is

$$\text{Summer ELF} = \frac{1089}{55 \times 24} = 82\%\ \text{(for 2002)}$$

These calculations show that the cooling equipment is operating beyond building occupancy (82% versus 33%) Therefore, excessive equipment run times should be investigated. Note that comparing the ELF to the occupancy factor is meaningless for buildings occupied 24 h a day, such as hospitals.

Similar tables and charts may be created for natural gas, water, and other utilities.



Year 1

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Actual kW	166	148	140	166	159	180	158	192	195	193	151	166
Billed kW	166	166	166	166	166	180	171	192	195	185	185	185

Year 2

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Actual kW	178	145	140	154	161	171	180	170	149	122	140	141
Billed kW	185	185	185	185	185	185	185	185	171	171	171	171

Year 3

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Actual kW	145	159	122	133	148	148	169	170	166	152	128	132
Billed kW	171	171	171	171	171	171	169	170	166	161	161	161

Fig. 3 Comparison Between Actual and Billed Demand for Atlanta Example Building

Electric Demand Billing

The Atlanta example building has a ratchet-type demand rate (see Chapter 56), and billed demand is determined as a percentage of actual demand in the summer months. The ratchet is illustrated in Figure 3, where billed demand is the greater of the measured demand or 95% of the highest measured demand within the past 12 months. The billed demand for January of year 3 was 171 kW (171 = 0.95 × 180), or 95% of the actual demand from July of year 2.

In Table 1, the actual demand in the first six months of 2003 had no effect on the billed demand, and therefore no effect on the dollar amount of the bill; the same is true for the last three months of the year. Because of the demand ratchet, the billed demand in January 2004 (171 kW) was set in July 2003. This means that any conservation measures that reduce peak demand will not affect billed demand until the following summer (e.g., June to September 2004); however, consumption savings begin at the next billing cycle. The effect of demand ratchet rates is that any conservation measures implemented have a longer initial payback period simply because of the utility rate structure. The energy manager should investigate other rate structures, such as a time-of-use (TOU) or seasonal rates. Rate structures for smaller buildings may not include demand charges.

Benchmarking Energy Use

Benchmarking (comparing a building's normalized energy consumption to that of similar buildings) can be a useful first measure of energy efficiency. Relative energy use is commonly expressed in **energy utilization index (EUI**; energy use per unit area per year) and **cost utilization index (CUI**; energy cost per unit area per year). The Atlanta example building is 30,700 ft^2 in size, so its 2004 EUI is 76,200 Btu/ft^2 and its CUI is \$1.47/ft^2.

Two sources of benchmarking data for U.S. buildings are ENERGY STAR (www.energystar.gov) and the U.S. Department of Energy's Energy Information Administration (DOE/EIA). Data on U.S. buildings in all sectors are summarized in periodic reports by the DOE/EIA. Tables 2 to 4 present DOE/EIA CBECS data in a combined format. Table 2 lists EUI input data and EUI distributions for the buildings surveyed in 2003. Table 3 lists the 2003 *Commercial Buildings Energy Consumption Survey* (CBECS) electricity per unit of floor area, and Table 4 shows CUI distributions. More complete and up-to-date information on the CBECS is available at www.eia.doe.gov/emeu/cbecs. When referring to these tables, keep in mind the facility's operating or occupied hours of facility and current utility rates.

Databases. Compiling a database of past energy use and cost is important. All reliable utility data should be examined. ASHRAE *Standard* 105 contains information that allows uniform, consistent expressions of energy consumption in new and existing buildings.

The energy use database for a new building may consist solely of typical data for similar buildings, as in Table 2. This may be supplemented by energy simulation data developed during design. A new building should be commissioned to ensure proper operation of all systems, including any energy-efficiency features (see ASHRAE *Guideline* 1.1 and Chapter 43).

All the data presented in these tables come from detailed reports of consumption patterns, and it is important to understand how they were derived. When using the data, verify correct use with the original EIA documents.

Mazzucchi (1992) lists data elements useful for normalizing and comparing utility billing information. Metered energy consumption and cost data are also published by trade associations, such as the Building Owners and Managers Association International (BOMA), the National Restaurant Association (NRA), and the American Hotel and Lodging Association (AH&LA). In some cases, local energy consumption data may be available from local utility companies or state or provincial energy offices.

Additional energy use information for homes and commercial buildings in Canada can be found at the Office of Energy Efficiency at http://www.oee.nrcan.gc.ca/corporate/statistics/neud/dpa/data_e/publications.cfm. In Europe, benchmarking data are defined on a national basis in the frame of the European Directive on the Energy Performance of Buildings (EPBD) (EC 2010). Balaras et al. (2007) provides an overview of relevant data for residential buildings, although detailed data for commercial buildings are rather limited (Gaglia et al 2007).

SURVEYS AND AUDITS

This section provides guidance on conducting building surveys and describes the levels of intensity of investigation.

Energy Audits

The objective of an energy audit is to identify opportunities to reduce energy use and/or cost. The results should provide the information needed by an owner/operator to decide which recommendations to implement. Energy audits may include the following:

1. Collect and analyze historical energy use
   - Review more than one year of energy bills (preferably three years)

Table 2 2003 Commercial Sector Floor Area and EUI Percentiles

Building Use	Calculated, Weighted: Number of Buildings, Hundreds	Calculated, Weighted: Floor Area, 10^9 ft^2	Actual Number of Buildings, *N*	Calculated, Weighted Energy Use Index (EUI) Values Site Energy, kBtu/yr per gross square foot — Percentiles: 10th	25th	50th	75th	90th	Mean
Administrative/professional office	442	6.63	555	28.1	41	62	93	138	75
Bank/other financial	104	1.10	75	55.7	67	87	117	184	106
Clinic/other outpatient health	66	0.75	100	28.7	41	66	97	175	84
College/university	34	1.42	88	14.1	67	108	178	215	122
Convenience store	57	0.16	28	68.6	156	232	352	415	274
Convenience store with gas station	72	0.28	32	82.2	135	211	278	409	225
Distribution/shipping center	155	5.25	231	8.7	17	33	54	91	45
Dormitory/fraternity/sorority	16	0.51	37	36.3	65	74	100	154	90
Elementary/middle school	177	4.75	331	21.1	35	54	93	127	76
Entertainment/culture	27	0.50	50	1.7	29	46	134	418	95
Fast food	78	0.26	95	176.3	268	418	816	933	534
Fire station/police station	53	0.38	47	6.9	24	82	112	137	78
Government office	84	1.55	150	31.5	52	77	103	149	85
Grocery store/food market	86	0.71	117	98.1	138	185	239	437	213
High school	68	2.52	126	19.8	44	65	99	130	75
Hospital/inpatient health	8	1.90	217	108.1	169	196	279	355	227
Hotel	20	1.90	86	39.7	51	73	116	183	95
Laboratory	9	0.65	43	98.0	165	270	505	925	362
Library	20	0.56	36	35.0	67	92	121	197	104
Medical office (diagnostic)	54	0.50	58	14.1	25	44	100	137	60
Medical office (nondiagnostic)	37	0.22	33	25.7	40	52	66	109	59
Mixed-use office	84	2.30	172	20.0	38	71	106	158	88
Motel or inn	70	1.05	109	23.9	37	67	102	197	87
Nonrefrigerated warehouse	229	3.05	172	2.3	6	19	46	87	34
Nursing home/assisted living	22	0.98	73	41.6	77	116	184	205	124
Other	70	1.08	68	5.5	29	69	96	118	74
Other classroom education	51	0.71	60	4.3	23	40	64	108	51
Other food sales	10	0.10	10	31.5	37	58	190	343	126
Other food service	58	0.33	56	39.6	71	125	309	548	242
Other lodging	16	0.65	28	31.2	54	71	83	146	76
Other office	73	0.41	52	15.3	41	57	84	146	69
Other public assembly	32	0.42	31	9.9	30	42	73	155	65
Other public order and safety	17	0.71	38	44.0	58	93	160	308	127
Other retail	47	0.24	42	32.7	65	92	146	205	120
Other service	139	0.48	171	28.0	50	86	164	303	168
Post office/postal center	19	0.50	23	7.2	58	64	76	97	64
Preschool/daycare	56	0.48	46	18.8	35	59	112	121	75
Recreation	96	1.28	99	13.4	24	40	88	152	68
Refrigerated warehouse	15	0.53	20	6.5	13	143	190	257	127
Religious worship	370	3.75	313	9.3	17	33	63	88	46
Repair shop	76	0.65	51	7.0	13	30	54	72	37
Restaurant/cafeteria	161	1.06	212	51.8	117	207	462	635	302
Retail store	347	3.48	460	14.2	25	45	93	170	72
Self-storage	198	1.26	84	2.1	4	7	10	15	9
Social/meeting	101	1.18	78	7.9	15	41	71	93	52
Vacant	182	2.57	178	1.4	3	12	31	77	26
Vehicle dealership/showroom	50	0.60	40	24.5	40	82	110	248	110
Vehicle service/repair shop	212	1.21	131	10.1	16	37	86	137	58
Vehicle storage/maintenance	176	1.21	99	0.9	4	21	53	152	54
SUM or Mean for sector	4645	64.78	5451	9.8	26	56	108	207	97

Source: Calculated based on DOE/EIA preliminary 2003 CBECS microdata.

- Review billing rate class options with utility
- Review monthly patterns for irregularities
- Derive target goals for energy, demand, and cost indices for a building with similar characteristics and climate

2. Study the building and its operational characteristics
   - Acquire a basic understanding of the mechanical and electrical systems
   - Perform a walk-through survey to become familiar with its construction, equipment, operation, and maintenance
   - Meet with owner/operator and occupants to learn of special problems or needs
   - Identify any required repairs to existing systems and equipment
3. Identify potential modifications to reduce energy use or cost
   - Identify low-cost/no-cost changes to the facility or to operating and maintenance procedures
   - Identify potential equipment retrofit opportunities
   - Identify training required for operating staff

Table 3 Electricity Index Percentiles from 2003 Commercial Survey

Building Use	Weighted Electricity Use Index Values, kWh/yr per gross square foot					
	Percentiles					
	10th	25th	50th	75th	90th	Mean
Administrative/professional office	3.54	6.7	11.0	15.0	24.1	12.7
Bank/other financial	6.23	14.5	22.2	29.5	33.3	22.5
Clinic/other outpatient health	4.94	9.4	15.2	20.7	27.3	16.6
College/university	4.13	10.5	15.0	24.0	42.3	17.7
Convenience store	20.09	43.3	65.3	78.7	107.4	69.6
Convenience store with gas station	24.09	37.7	48.1	79.0	120.0	62.0
Distribution/shipping center	1.77	2.9	4.5	7.4	9.9	5.7
Dormitory/fraternity/sorority	2.16	3.3	5.1	6.6	16.6	6.7
Elementary/middle school	3.45	5.7	9.3	14.0	19.7	12.1
Entertainment/culture	0.49	1.0	7.4	16.9	122.5	20.9
Fast food	27.97	48.0	81.8	131.2	168.1	95.5
Fire station/police station	1.14	3.8	6.6	12.6	22.0	9.8
Government office	3.96	8.1	10.8	19.3	26.0	14.3
Grocery store/food market	26.12	32.2	42.4	54.4	100.6	51.7
High school	3.50	4.5	7.5	12.8	19.3	9.7
Hospital/inpatient health	15.24	21.8	24.0	35.6	45.9	28.7
Hotel	6.73	11.6	14.3	18.3	27.4	16.4
Laboratory	11.43	25.5	39.2	54.6	95.6	44.1
Library	6.34	8.7	15.5	23.2	34.3	17.3
Medical office (diagnostic)	2.21	4.1	7.6	13.8	18.3	9.6
Medical office (nondiagnostic)	2.41	4.5	7.4	12.1	15.3	8.6
Mixed-use office	3.40	5.5	11.1	18.0	28.9	14.3
Motel or inn	4.95	7.5	10.8	18.1	26.3	13.6
Nonrefrigerated warehouse	0.38	1.0	2.9	5.9	10.7	5.4
Nursing home/assisted living	6.33	8.1	14.9	21.0	25.9	15.9
Other	1.60	3.0	5.8	12.2	24.7	9.5
Other classroom education	1.27	2.8	4.9	9.2	15.7	6.6
Other food sales	9.22	9.2	10.8	12.6	58.5	22.0
Other food service	8.85	15.4	27.2	60.1	89.5	40.3
Other lodging	2.86	3.7	14.0	21.0	22.7	12.0
Other office	3.04	4.5	9.4	16.2	18.3	10.8
Other public assembly	1.13	2.6	3.4	12.3	13.8	7.5
Other public order and safety	5.45	14.4	16.7	20.7	42.1	18.9
Other retail	4.87	6.7	22.4	27.2	38.3	19.8
Other service	4.13	7.5	13.4	19.6	28.6	16.3
Post office/postal center	2.10	3.2	7.2	13.3	21.3	9.9
Preschool/daycare	3.34	5.5	8.8	12.1	28.9	11.6
Recreation	1.59	2.9	5.1	10.8	19.3	8.8
Refrigerated warehouse	1.89	3.8	35.2	51.1	55.7	28.5
Religious worship	1.06	1.9	3.5	6.0	8.6	4.5
Repair shop	1.88	2.6	6.1	7.6	14.2	6.8
Restaurant/cafeteria	9.76	15.2	28.7	49.9	88.2	37.9
Retail store	2.41	3.9	8.1	15.2	27.3	12.5
Self-storage	0.63	1.2	2.1	2.8	3.8	2.2
Social/meeting	1.01	1.8	2.9	7.5	12.8	6.2
Vacant	0.29	0.4	1.7	3.8	7.8	3.2
Vehicle dealership/showroom	2.50	7.2	13.8	21.9	33.9	15.7
Vehicle service/repair shop	1.96	3.3	5.6	9.8	18.6	8.2
Vehicle storage/maintenance	0.27	1.2	3.3	6.4	10.4	5.2
SUM or Mean for sector	1.59	3.6	8.3	17.1	35.4	15.7

Source: Calculated based on DOE/EIA preliminary 2003 CBECS microdata.

- Perform a rough estimate of the breakdown of energy consumption for significant end-use categories

4. Perform an engineering and economic analysis of potential modifications
   - For each practical measure, determine resultant savings
   - Estimate effects on building operations and maintenance costs
   - Prepare a financial evaluation of estimated total potential investment
5. Prepare a rank-ordered list
   - List all possible energy savings modifications
   - Select those that may be considered practical by the building owner
   - Assume that modifications with highest operational priority and/or best return on investment will be implemented first
   - Provide preliminary implementation costs and savings estimates
   - Assume that modifications with highest operational priority and/or best return on investment will be implemented first
6. Report results
   - Provide description of building, operating requirements, and major energy-using systems
   - Clearly state savings from each modification and assumptions on which each is based
   - Review list of practical modifications with the owner
   - Prioritize modifications in recommended order of implementation
   - Recommend measurement and verification methods

Table 4 Electricity Index Percentiles from 2003 Commercial Survey

	Weighted Electricity Use Index Values, kWh/yr per gross square foot					
	Percentiles					
Building Use	10th	25th	50th	75th	90th	Mean
Administrative/professional office	3.54	6.7	11.0	15.0	24.1	12.7
Bank/other financial	6.23	14.5	22.2	29.5	33.3	22.5
Clinic/other outpatient health	4.94	9.4	15.2	20.7	27.3	16.6
College/university	4.13	10.5	15.0	24.0	42.3	17.7
Convenience store	20.09	43.3	65.3	78.7	107.4	69.6
Convenience store with gas station	24.09	37.7	48.1	79.0	120.0	62.0
Distribution/shipping center	1.77	2.9	4.5	7.4	9.9	5.7
Dormitory/fraternity/sorority	2.16	3.3	5.1	6.6	16.6	6.7
Elementary/middle school	3.45	5.7	9.3	14.0	19.7	12.1
Entertainment/culture	0.49	1.0	7.4	16.9	122.5	20.9
Fast food	27.97	48.0	81.8	131.2	168.1	95.5
Fire station/police station	1.14	3.8	6.6	12.6	22.0	9.8
Government office	3.96	8.1	10.8	19.3	26.0	14.3
Grocery store/food market	26.12	32.2	42.4	54.4	100.6	51.7
High school	3.50	4.5	7.5	12.8	19.3	9.7
Hospital/inpatient health	15.24	21.8	24.0	35.6	45.9	28.7
Hotel	6.73	11.6	14.3	18.3	27.4	16.4
Laboratory	11.43	25.5	39.2	54.6	95.6	44.1
Library	6.34	8.7	15.5	23.2	34.3	17.3
Medical office (diagnostic)	2.21	4.1	7.6	13.8	18.3	9.6
Medical office (nondiagnostic)	2.41	4.5	7.4	12.1	15.3	8.6
Mixed-use office	3.40	5.5	11.1	18.0	28.9	14.3
Motel or inn	4.95	7.5	10.8	18.1	26.3	13.6
Nonrefrigerated warehouse	0.38	1.0	2.9	5.9	10.7	5.4
Nursing home/assisted living	6.33	8.1	14.9	21.0	25.9	15.9
Other	1.60	3.0	5.8	12.2	24.7	9.5
Other classroom education	1.27	2.8	4.9	9.2	15.7	6.6
Other food sales	9.22	9.2	10.8	12.6	58.5	22.0
Other food service	8.85	15.4	27.2	60.1	89.5	40.3
Other lodging	2.86	3.7	14.0	21.0	22.7	12.0
Other office	3.04	4.5	9.4	16.2	18.3	10.8
Other public assembly	1.13	2.6	3.4	12.3	13.8	7.5
Other public order and safety	5.45	14.4	16.7	20.7	42.1	18.9
Other retail	4.87	6.7	22.4	27.2	38.3	19.8
Other service	4.13	7.5	13.4	19.6	28.6	16.3
Post office/postal center	2.10	3.2	7.2	13.3	21.3	9.9
Preschool/daycare	3.34	5.5	8.8	12.1	28.9	11.6
Recreation	1.59	2.9	5.1	10.8	19.3	8.8
Refrigerated warehouse	1.89	3.8	35.2	51.1	55.7	28.5
Religious worship	1.06	1.9	3.5	6.0	8.6	4.5
Repair shop	1.88	2.6	6.1	7.6	14.2	6.8
Restaurant/cafeteria	9.76	15.2	28.7	49.9	88.2	37.9
Retail store	2.41	3.9	8.1	15.2	27.3	12.5
Self-storage	0.63	1.2	2.1	2.8	3.8	2.2
Social/meeting	1.01	1.8	2.9	7.5	12.8	6.2
Vacant	0.29	0.4	1.7	3.8	7.8	3.2
Vehicle dealership/showroom	2.50	7.2	13.8	21.9	33.9	15.7
Vehicle service/repair shop	1.96	3.3	5.6	9.8	18.6	8.2
Vehicle storage/maintenance	0.27	1.2	3.3	6.4	10.4	5.2
SUM or Mean for sector	1.59	3.6	8.3	17.1	35.4	15.7

Source: Calculated based on DOE/EIA preliminary 2003 CBECS microdata.

ASHRAE (2004) identifies the following four levels of effort in the audit process.

Preliminary Energy Use Analysis. This involves analysis of historic utility use and cost and development of the energy utilization index (EUI) of the building. Compare the building's EUI to similar buildings to determine if further engineering study and analysis are likely to produce significant energy savings.

Level I: Walk-Through Analysis. This assesses a building's current energy cost and efficiency by analyzing energy bills and briefly surveying the building. The auditor should be accompanied by the building operator. Level I analysis identifies low-cost/no-cost measures and capital improvements that merit further consideration, along with an initial estimate of costs and savings. The level of detail depends on the experience of the auditor and the client's specifications. The Level I audit is most applicable when there is some doubt about the energy savings potential of a building, or when an owner wishes to establish which buildings in a portfolio have the greatest potential savings. The results can be used to develop a priority list for a Level II or III audit.

Level II: Energy Survey and Analysis. This includes a more detailed building survey and energy analysis, including a breakdown of energy use in the building, a savings and cost analysis of all practical measures that meet the owner's constraints, and a discussion of any effect on operation and maintenance procedures. It also lists potential capital-intensive improvements that require more thorough data collection and analysis, along with an initial judgment of potential costs and savings. This level of analysis is adequate for most buildings.

Level III: Detailed Analysis of Capital-Intensive Modifications. This focuses on potential capital-intensive projects identified during Level II and involves more detailed field data gathering and engineering analysis. It provides detailed project cost and savings information with a level of confidence high enough for major capital investment decisions.

The levels of energy audits do not have sharp boundaries. They are general categories for identifying the type of information that can be expected and an indication of the level of confidence in the results. In a complete energy management program, Level II audits should be performed on all facilities.

A thorough systems approach produces the best results. This approach has been described as starting at the end rather than at the beginning. For example, consider a factory with steam boilers in constant operation. An expedient (and often cost-effective) approach is to measure the combustion efficiency of each boiler and to improve boiler efficiency. Beginning at the end requires finding all or most of the end uses of steam in the plant, which could reveal considerable waste by venting to the atmosphere, defective steam traps, uninsulated lines, and lines through unused heat exchangers. Eliminating end-use waste can produce greater savings than improving boiler efficiency.

A detailed process for conducting audits is outlined in ASHRAE (2004).

IMPROVING DISCRETIONARY OPERATIONS

Basic Energy Management

Control Energy System Use. The most effective method to reduce energy costs is through discretionary operations, such as turning off equipment when not needed. Ways to conserve energy include the following:

- Shut down HVAC&R systems when not required
- Reduce air leakage
- Reduce ventilation rates during periods of low occupancy
- Shut down exhaust fans when not required
- Seal or repair leaks in ducts and pipes
- Reduce water leakage
- Turn off lighting: remove unnecessary lighting, add switched circuits, use motion sensors and light-sensitive controls
- Use temperature setup and setback
- Cool with outside air
- Seal unused vents and ducts to the outside
- Tune up systems before heating and cooling seasons
- Take transformers offline during idle periods

Purchase Lower-Cost Energy. This is the second most effective method for reducing energy costs. Building operators and managers must understand all the options in purchasing energy and design systems to take advantage of changing energy costs. The following options should be considered:

- Choosing or negotiating lower-cost utility rates
- Procuring electricity or fuels through brokers
- Correcting power factor penalties
- Controlling peak electric billing demand
- Utility-sponsored demand response programs
- Transportation and interruptible natural gas rates
- Cogeneration
- Lower-cost liquid fuels
- Increasing volume for onsite storage
- Avoiding sales or excise taxes where possible
- Incentive rebates from utilities and manufacturers

Optimize Energy Systems Operation. The third most effective method for reducing energy costs is to tune energy systems to optimal performance, an ongoing process combining training, preventive maintenance, and system adjustment. Tasks for optimizing performance include

- Training operating personnel
- Tuning combustion equipment
- Adjusting gas burners to optimal efficiency
- Following an established maintenance program
- Cleaning or replacing filters
- Cleaning fan blades and ductwork
- Cycling ventilation systems to coincide with occupied spaces
- Using water treatment

Purchase Efficient Replacement Systems. This method is more expensive than the other three, presents energy managers with the greatest liability, and may be less cost-effective. It is critical to ensure that possible equipment or system replacements are objectively evaluated to confirm both the replacement costs and benefits to the owner. The optimum time for replacing less-efficient equipment is near the end of its expected life or when major repairs are needed. Systems commonly replaced include

- Lighting systems and lamps
- Heating and cooling equipment
- Energy distribution systems (pumps and fans)
- Motors
- Thermal envelope components
- Controls and energy management systems

Optimizing More Complex System Operation

As the complexity of building systems increases, additional strategies are needed to optimize energy systems. According to ASHRAE *Guideline* 0-2005, approaches include **recommissioning** (applied to a project that has been delivered using the commissioning process), **retrocommissioning** (applied to an existing facility that was not previously commissioned), and **ongoing commissioning** (continuation of the commissioning process well into the occupancy and operations phase to verify that a project continues to meet current and evolving owner's project requirements). See Chapter 43 for more information.

These approaches typically require a strong team effort of the facility staff and third-party consultants to identify and fix comfort problems as well as aggressively optimize HVAC operation and control. Some important measures typically implemented include

- Optimizing hot and cold deck reset schedules
- Optimizing duct static pressure reset schedules
- Optimizing pump control
- Optimizing terminal box settings/control
- Optimizing sequencing and water temperature reset schedules of boilers and chillers
- Identifying and repairing stuck or leaky valves and dampers
- Training operating personnel in optimum operating strategies
- Setting up monitoring and reporting of key system performance indicators

Implementing these measures has been found to reduce energy use by an average of about 20% (Claridge et al. 1998). Approaches to commissioning and optimizing operation of existing buildings can be found in ASHRAE *Guideline* 1.1-2007, Claridge and Liu (2000), Haasl and Sharp (1999), Kurt et al. (2003), Liu et al. (1997), Poulos (2007), and Tseng (2005).

ENERGY-EFFICIENCY MEASURES

Identifying Energy-Efficiency Measures

Various energy-efficiency measures (EEMs) can be quantitatively evaluated from end-use energy profiles. Important considerations in this process are as follows:

- System interaction
- Utility rate structure

- Payback
- Alignment with corporate goals
- Installation requirements
- Life of the measure
- Energy measurement and verification requirements
- Maintenance costs
- Tenant/occupant comfort
- Effect on building operation and appearance

Accurate energy savings calculations can be made only if system interaction is allowed for and fully understood. Annual simulation models may be necessary to accurately estimate the interactions between various EEMs.

Using average costs per unit of energy in calculating the energy cost avoidance of a particular measure is likely to result in incorrect energy costs and cost avoidance, because actual energy cost avoidance may not be proportional to the energy saved, depending on the billing method for energy used.

PNNL (1990) discusses 118 EEMs, including the following:

Boilers	Condensate systems
Envelope infiltration	Water treatment
Weather-stripping	Caulking
Fuel systems	Vestibules
Chillers	Steam distribution
Vapor barrier	Hydronic systems
Glazing	Pumps
Piping insulation	Steam traps
Instrumentation	Domestic water heating
Shading	Fixtures
Thermal shutters	Swimming pools
Surface color	Cooling towers
Roof covering	Condensing units
Lamps	Air-handling units
Ballasts	Unitary equipment
Light switching options	Outside air control
Photo cell controls	Balancing
Demand limiting	Shutdown
Power factor correction	Minimizing reheat
Energy recovery	Power distribution
Filters	Cooking practices
Humidification	Refrigeration
Dishwashing	System air leakage
Vending machines	System interaction
Heat/cool storage	Space segregation
Time-of-day rates	Computer controls
Cogeneration	Heat pumps
Active solar systems	Staff training
Occupant indoctrination	Documentation
Controls	Thermostats
Setback	Space planning
T5 lighting	Variable-frequency drives

In addition, previously implemented energy-efficiency measures should be evaluated to (1) ensure that devices are in good working order and measures are still effective, and (2) consider revising them to reflect changes in technology, building use, and/or energy cost.

Evaluating Energy-Efficiency Measures

In establishing EEM priorities, the capital cost, cost-effectiveness, effect on indoor environment, and resources available must be considered. Factors involved in evaluating the desirability of energy-efficiency measures are as follows:

- Rate of return (simple payback, life-cycle cost, net present value)
- Total savings (energy, cost avoidance)
- Initial cost (required investment)
- Other benefits (safety, comfort, improved system reliability, improved productivity)
- Liabilities (increased maintenance costs, potential obsolescence)
- Risk of failure (confidence in predicted savings, rate of increase in energy costs, maintenance complications, success of others with the same measures)

Project success also depends on the availability of

- Management attention, commitment, and follow-through
- Technical expertise
- Personnel
- Investment capital

Some owners are reluctant to implement EEMs because of bad experiences with energy projects. To reduce the risk of failure, documented performance of EEMs in similar situations should be obtained and evaluated. One common problem is that energy consumption for individual end uses is overestimated, and the predicted savings are not achieved. When doubt exists about energy consumption, temporary monitoring or spot measurements should be made and evaluated.

Heating Effects of Electrical Equipment

Electrical equipment and appliances, from lighting systems and office equipment to motors and water heaters, provide useful services; however, the electrical energy they use eventually appears as heat within the building, which can either be useful or detrimental, depending on the season. In cold weather, heat produced by electrical equipment can help reduce the load on the building's heating system. In contrast, during warm weather, it adds to the air-conditioning load.

Energy-efficient equipment and appliances consume less energy to produce the same useful work, but they also produce less heat. As a result, efficient electrical equipment increases the load on heating systems in winter and reduces the load on air-conditioning systems in summer. Effects of energy-efficient equipment and appliances on energy use for building heating and air conditioning systems are commonly called **interactive effects** or **cross effects**.

When considering the overall net savings of an energy-efficiency measure, it is important to consider its interactive effects on building heating, cooling, and refrigeration systems. Weighing the interactive effects results in better-informed decisions and realistic expectations of savings.

The percentage of heat that is useful in a specific building or room depends on several factors, including the following:

- Location of light fixtures
- Location of heaters and their thermostats or other sensors
- Type of ceiling
- Size of building
- Whether room is an interior or exterior space
- Extent of heating and cooling seasons
- Type of heating, ventilation, and air-conditioning system used in each room

Unfortunately, interactive effects are often quite complex and may require assessment by a specialist; for details, see Rundquist et al. (1993).

Exploring Financing Options

Financing alternatives also need to be considered. When evaluating proposed energy management projects, particularly those with a significant capital cost, it is important to include a life-cycle cost analysis. This not only provides good information about the financial attractiveness (or otherwise) of a project, but also assures management that the project has been carefully considered and evaluated before presentation.

Several life-cycle cost procedures are available. Chapter 37 contains details on these and other factors that should be considered in such an analysis.

Capital for energy-efficiency improvements is available from various public and private sources, and can be accessed through a wide and flexible range of financing instruments. There are variations and combinations, but the five general mechanisms for financing investments in energy efficiency are the following:

- **Internal funds**, or direct allocations from an organization's own internal capital or operating budget
- **Debt financing**, with capital borrowed directly by an organization from private lenders
- **Lease** or **lease-purchase agreements**, in which equipment is acquired through an operating or financing lease with little or no up-front costs, and payments are made over five to ten years
- **Energy performance contracts**, in which improvements are financed, installed, and maintained by a third party, which guarantees savings and payments based on those savings
- **Utility (or other) incentives**, such as rebates, grants, or other financial assistance offered by an energy utility or public benefits fund for design and purchase of energy-efficient systems and equipment

An organization may use several of these financing mechanisms in various combinations. The most appropriate set of options depends on the type of organization (public or private), size and complexity of a project, internal capital constraints, in-house expertise, and other factors (Turner 2001).

IMPLEMENTING ENERGY-EFFICIENCY MEASURES

When all desirable EEMs have been considered and a list of recommendations is developed, a report should be prepared for management. Each recommendation should include the following:

- Present condition of the system or equipment to be modified
- Recommended action
- Who should accomplish the action
- Necessary documentation or follow-up required
- Measurement and verification protocol to be used
- Potential interferences to successful completion
- Disruption to workplace or production
- Staff effort and training required
- Risk of failure
- Interactions with other end uses and EEMs
- Economic analysis (including payback, investment cost, and estimated savings figures) using corporate economic evaluation criteria
- Schedule for implementation

The energy manager must be prepared to sell the plans to upper management. Energy-efficiency measures must generally be financially justified if they are to be adopted. Every organization has limited funds available that must be used in the most effective way. The energy manager competes with others in the organization for the same funds. A successful plan must be presented in a form that is easily understood by the decision makers. Finally, the energy manager must present nonfinancial benefits, such as improved product quality or the possibility of postponing other expenditures.

After approval by management, the energy manager directs the completion of energy-efficiency measures. If utility rebates are used, the necessary approvals should be acquired before proceeding with the work. Some measures require that an architect or engineer prepare plans and specifications for the retrofit. The package of services required usually includes drawings, specifications, assistance in obtaining competitive bids, evaluation of the bids, selection of contractors, construction observation, final check-out, and assistance in training personnel in the proper application of the revisions.

MONITORING RESULTS

Once energy-efficiency measures are under way, procedures need to be established to record, frequently and regularly, energy consumption and costs for each building and/or end-use category in a manner consistent with functional cost accountability. Turner et al. (2001) found that consumption increased by more than 5% over two years because of component failures and controls changes after implementing optimum practices in a group of 10 buildings. Data may be obtained from the utility, but additional metering may be needed to monitor energy consumption accurately. Metering can use devices that automatically read and transmit data to a central location, or less expensive metering devices that require regular readings by building maintenance and/or security personnel. Costs for automatic metering devices, such as adding points to a DDC system, must be weighed against the benefits. Many energy managers find it helpful to collect energy consumption information hourly.

The energy manager should review data while they are current and take immediate action if profiles indicate a trend in the wrong direction. These trends could be caused by uncalibrated controls, changes in operating practices, or mechanical system failure, which should be isolated and corrected as soon as possible.

EVALUATING SUCCESS AND ESTABLISHING NEW GOALS

Comparing facility performance before and after implementing EEMs helps keep operating staff on track with their energy-efficiency efforts, ensuring that performance is maintained. Evaluating and reporting energy performance involves four steps:

1. Establishing key performance indicators
2. Tracking performance
3. Developing new goals
4. Reporting

Establishing Key Performance Indicators

It is important to determine performance factors of the energy management program. These are expressed in terms of key performance indicators (KPIs). The definition of key performance indicators determines what data need to be collected, how often to collect it, and how to present it to senior management. Suggested basic key performance indicators are

- Energy use index (EUI), total energy use per unit of gross floor area
- Cost utilization index (CUI), total energy cost per unit of total gross floor area
- Electrical energy use per unit of total gross floor area

Energy Policy Act. The Energy Policy Act (EPAct 2005) set goals for federal buildings to decrease their energy consumption by 2% per year between 2006 and 2015, compared to a baseline of 2004 consumption. Thus, by 2010, for example, the target percentage reduction from 2004 values was 10%. For this initiative, the following sample KPI definitions could be used:

- 2004 benchmark measurement (energy use per unit area) reduced by 4% to set 2007 target, and by 10% to set the 2010 target, and by 16% to set the 2013 target
- Energy use data, summed monthly and annually for reporting against targets

Executive Order 13514 October 2009. Executive Order 13514 further set goals for U.S. federal agencies to develop and implement strategic energy sustainability plans for 2011 through 2021 to reduce buildings' energy use intensity (EUI), increase renewable energy use, obtain net-zero-energy buildings by 2030, and ensure that all products and services are ENERGY STAR or Federal Energy Management Program (FEMP) designated.

ENERGY STAR Tools. The U.S. Environmental Protection Agency's (EPA) ENERGY STAR web site offers the free online benchmarking tool, Target Finder (I-P units only; accessible from www.energystar.gov/index.cfm?c=new_bldg_design.bus_target_finder). This tool compares actual building performance to target values, and to other similar buildings. Figure 4 shows sample results for the Atlanta example building's general office space (omitting the computer center's floor space and electricity use). ENERGY STAR also offers an online Portfolio Manager (www.energystar.gov/index.cfm?c=evaluate_performance.bus_portfoliomanager), which provides secure performance data management and benchmarking for multiple buildings. Annual benchmarking with these (or similar) tools helps track improvements, both over time and in comparison with other buildings.

Building Energy Labels

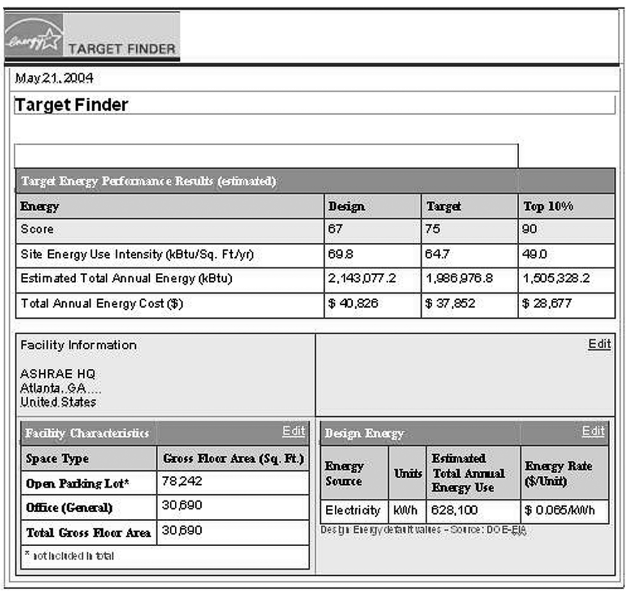
The ASHRAE Building Energy Quotient (eQ) labeling program rates new and existing buildings (Jarnagin 2009). Like the EPA's ENERGY STAR program, Building eQ focuses solely on energy, but provides additional features, including potential side-by-side comparison of operational and asset (as-designed) ratings; peak-demand reduction and demand management opportunities; on-site renewable energy; indoor environmental quality indicators; and a list of operational features, including commissioning activities, energy-efficiency improvements, and information on improving performance. The Building eQ scale allows differentiation among buildings at the highest levels of performance and encourages the design and operation of net-zero-energy buildings.

The Building eQ program provides an easily understood scale to convey a building's energy use to the public. Through an on-site assessment, the building owner is provided with building-specific information that can be used to improve the building. Documentation on previous energy-efficiency upgrades and commissioned systems is also included. With procedures for both an asset and operational rating, building owners can make side-by-side comparisons that could further reconcile differences between designed and measured energy use.

The label itself is the most visible aspect of the program (Figure 5). It is simple to understand and is targeted at the general public. It could be posted in a building lobby and could satisfy compliance with many of the programs being developed at the state and local level requiring display of energy use. The certificate contains technical information that explains the score on the label and provides information useful to the building owner, prospective owners and tenants, and operations and maintenance personnel. This includes many of the value-added features described previously. The documentation accompanying the label and certificate provides background information useful for engineers, architects, and technically savvy building owners or prospective owners in determining the current state of the building and opportunities for improving its energy use. More information is available at http://buildingeq.com/.

Throughout the European Union, the European Commission's directive on the energy performance of buildings (EPBD) has been in effect since January 4, 2006. Despite difficulties, all EU member states have brought into force national laws, regulations, and administrative provisions for setting minimum requirements on the energy performance of new buildings and for existing buildings that are being renovated, as well as energy performance certification of buildings. Additional requirements include regular inspection of building systems and installations, assessment of existing facilities, and provision of advice on possible improvements and alternative solutions. The objective is to properly design new buildings and renovate existing buildings in a manner that will use the minimum nonrenewable energy, produce minimum air pollution as a result of the building operating systems, and minimize construction waste, all with acceptable investment and operating costs, while improving the indoor environment for comfort, health, and safety.

An energy performance certificate (EPC) is issued when buildings are constructed, sold, or rented out. The EPC documents the energy performance of the building, expressed as a numeric indicator that allows benchmarking. The certificate includes recommendations for cost-effective improvement of the energy performance, and it is valid for up to 10 years.


TARGET FINDER

May 21, 2004

Target Finder

Target Energy Performance Results (estimated)			
Energy	**Design**	**Target**	**Top 10%**
Score	67	75	90
Site Energy Use Intensity (kBtu/Sq. Ft/yr)	69.8	64.7	49.0
Estimated Total Annual Energy (kBtu)	2,143,077.2	1,986,976.8	1,505,328.2
Total Annual Energy Cost ($)	$ 40,826	$ 37,852	$ 28,677

Facility Information Edit

ASHRAE HQ
Atlanta, GA ...
United States

Facility Characteristics Edit

Space Type	Gross Floor Area (Sq. Ft.)
Open Parking Lot*	78,242
Office (General)	30,690
Total Gross Floor Area	30,690

* not included in total

Design Energy Edit

Energy Source	Units	Estimated Total Annual Energy Use	Energy Rate ($/Unit)
Electricity	kWh	628,100	$ 0.065/kWh

Design Energy default values - Source: DOE-EIA

Fig. 4 ENERGY STAR Rating for Atlanta Building

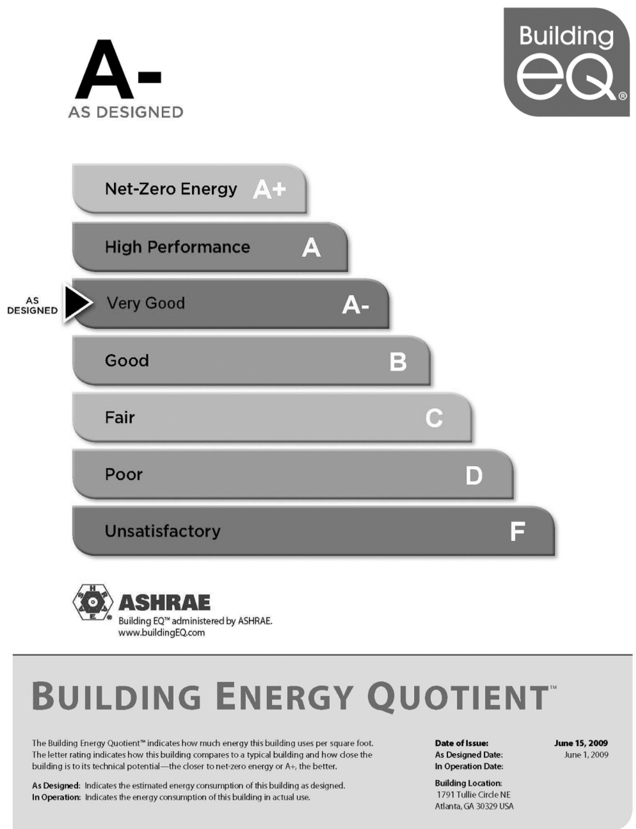


Fig. 5 ASHRAE Building eQ Label

According to the EPBD, minimum energy performance requirements are set for new buildings and for major renovations of large existing buildings in each EU member state. Energy performance should be upgraded to meet minimum requirements that are technically, functionally, and economically feasible. In the case of large new buildings, alternative energy supply systems should be considered (e.g., decentralized energy supply systems based on renewable energy, combined heat and power, district or block heating or cooling, heat pumps). The concerted action (CA) EPBD that was launched by the European Commission provides updated information on the implementation status in the various European countries (www.epbd-ca.org).

Tracking Performance

The next step is to create a tracking mechanism to provide high-level KPI views, giving an overall indication of energy performance. Daily monitoring can be a valuable, proactive tool. Most DDC systems can monitor energy performance and notify the energy engineer when energy usage is off track.

For example, using the data presented in Table 1, a daily target usage/day could be determined based on outside air temperature and building occupancy schedule. If the daily use rises above the target use by a predetermined amount, the DDC system can indicate an alarm and send a notification. The energy manager can then investigate the cause of the discrepancy and correct any operational errors before long-term performance is affected. When implementing this type of performance-monitoring strategy, it is important that the measurement and verification plan provide standard operating procedures (SOPs) to facilitate troubleshooting of energy performance alarms. Procedures are discussed in ANSI/ASHRAE *Standard* 105.

Establishing New Goals

Implementing the baseline model is a three-step process: (1) the baseline period is selected, (2) the baseline model is created, and (3) one or more target models are identified to track energy performance. The baseline period should most closely reflect the current or expected building use and occupancy. Utility bill data can be used to create a steady-state baseline model of energy consumption for each building. Steady-state models are useful when using monthly, weekly, or daily data. Utility bills for an entire year are collected and used for baseline development. Many energy managers use spreadsheets to compile and compare the data. For more information on energy estimating using steady-state, data-driven models, see Chapter 19 of the 2009 *ASHRAE Handbook—Fundamentals*.

Cooling degree-days and heating degree-days are commonly used to track successes compared to EEM targets with respect to weather-dependent energy consumption. Local CDD and HDD information is traditionally based on a balance point of 65°F, which is not typically the actual balance point for any commercial or residential building; therefore, regional or local HDD values are only a general reference point. A building's weather-affected energy consumption may be calculated by using spreadsheets, regression analysis, or building energy modeling software.

For larger, more complex facilities, regression analysis can be used to analyze energy consumption if the energy manager has the analytical expertise. Through linear regression, utility bills are normalized to their daily average values. Repeated regression is done until the regression data represent the best fit to the utility bill data. Figure 6 shows the scatter plot of a best-fit baseline and target models. In this example, cooling degree-days significantly affected building energy consumption, with a best fit for a base temperature (balance point) of 54°F (Sonderegger 1998). Reducing the slope and intercept constants of the baseline by 20% creates a straight-line model equation that represents a target goal for a 20% energy reduction.

The utility bill data steady-state model is also referred to as whole-building measurement and verification. More information about this process can be found in ASHRAE *Guideline* 14 and EVO (2002).

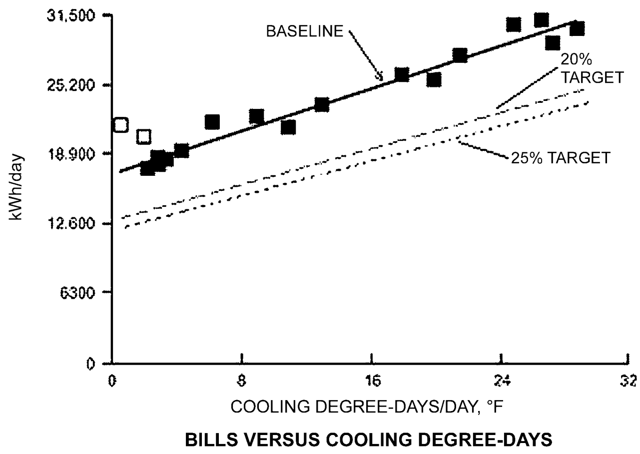


Fig. 6 Scatter Plot, Showing Best-Fit Baseline Model and Target Models

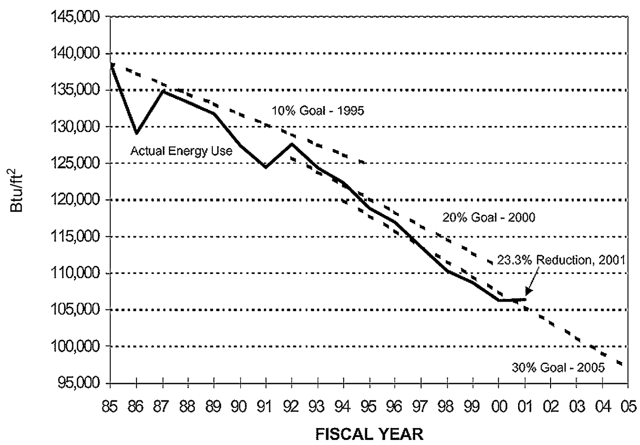


Fig. 7 Progress Toward Energy Reduction Goals for Federal Standard Buildings

Reporting

When developing presentation materials to document energy performance, make sure that report content shows performance as related to key performance indicators (KPIs) used by the organization. Reports should be pertinent to the audience. Whereas a report to the company's administration would show how the energy management program affects operating and maintenance costs, a separate report to the operations staff might show how their daily decisions and actions change daily load profiles.

Figure 7 shows progress toward energy reduction goals for federal buildings presented to the U.S. Congress for fiscal year 2001 (DOE 2004). The figure compares energy performance against energy goals established in 1999.

Reports must be easy to understand by their readers. Keep management aware of the progress of changes to resource consumption, utility costs, and any effects (positive or negative) on the indoor environment as perceived by staff. Provide information on any major activities, savings to date, and future planned activities. Provide narrative reports with pie charts or bar graphs of cost per resource. Figure 8 shows an example of monthly gas use in a facility from year to year.

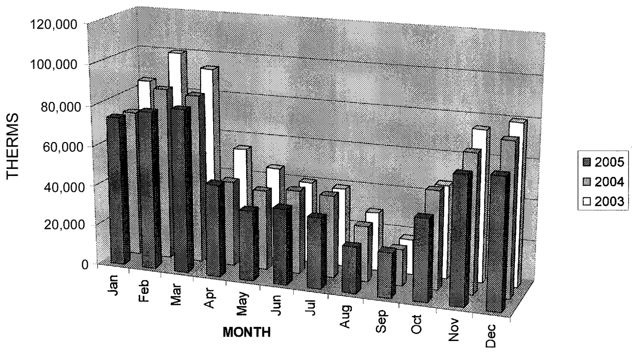


Fig. 8 Monthly Comparison of Natural Gas Use by Year

BUILDING EMERGENCY ENERGY USE REDUCTION

This section provides information to help building owners and operators maintain the best operating condition for the facilities during various energy emergencies. The need for occasional short-term reductions in energy use has increased because of rising energy costs and supply reductions (voluntary or mandatory) or equipment failures. In limited instances, utilities have implemented rolling blackouts, requested voluntary reductions, and asked users to operate emergency generators.

Implementing Emergency Energy Use Reductions

Each building manager or operator should use the energy team approach and identify an individual with the necessary authority and knowledge to review and fit recommendations into a building energy management plan. Because energy reduction requirements may occur with little or no advance notice, contingency plans should be developed and reviewed by the energy team. Each type of energy emergency requires a specific plan to reduce building energy use and still maintain the best possible building environment. The plan should include measures to reduce specific types of energy use in the building, as well as provisions for both slight and major energy use reduction. In some cases, existing building energy management systems can be used to implement demand shedding. The plan should be tested regularly. The following steps should be taken in developing a building emergency energy use reduction plan:

1. Develop a list of measures applicable to each building.
2. Estimate the amount and type of energy savings for each measure and appropriate combination of measures (e.g., account for air-conditioning savings from reduced lighting and other internal loads). Tabulate demand and usage savings separately for response to different types of emergencies.
3. For various levels of possible energy emergency, develop a plan that maintains the best building environment under the circumstances. Develop the plan so that actions taken can be energy-source-specific. That is, group actions to be taken to reduce energy consumption for each type of energy used in the building. Include both short- and long-term measures in the plan. Operational changes may be implemented quickly and prove adequate for short-term emergencies.
4. Experiment with the plan; record energy consumption and demand reduction data, and revise the plan as necessary. Much of the experimentation may be done on weekends to minimize disruption.
5. Meet with the local utility provider(s) and back-up fuel suppliers to review the plan.
6. Meet with building occupants annually to review the plan to ensure that actions taken do not cause major disruptions or compromise life safety or security provisions. Establish a procedure for notification of building occupants before actions are taken.
7. Be certain that there is a plan to minimize entrapment of occupants in elevators in case of emergency disruptions.
8. Review the plan annually with building security and the fire department to ensure that emergency efforts are not hindered by the plan and that security or emergency people know what to expect (reduced lighting, lower temperatures, elevators out of operation, etc.).
9. When preparing the plan, **do not**
   - Take lighting fixtures out of service that are on night lighting circuits, provide lighting for security cameras, or provide egress lighting during a power failure
   - Remove elevators or lifts from service that will be required for emergency or ADA purposes
   - Reduce ventilation or exhaust in laboratories or other areas where hazardous conditions exist

Some measures can be implemented permanently. Depending on the level of energy emergency and the building priority, the following actions may be considered in developing the plan for emergency energy reduction:

General

- Change operating hours
- Move personnel into other building areas (consolidation)
- Ensure that emergency generators are tuned up and run frequently enough to increase dependability, service the expected electrical load, and keep alternative fuel supply at optimal level
- Shut off nonessential equipment
- Review the amount of uninterruptible power supply (UPS) time available for critical equipment, and upgrade if necessary

Thermal Envelope

- Use all existing blinds, draperies, and window coverings
- Install interior window insulation
- Caulk and seal around unused exterior doors and windows (but do not seal doors required for emergency egress or that may be required by the fire department in an emergency).
- Install solar shading devices in summer
- Seal all unused vents and ducts to outside

HVAC Systems and Equipment

- Modify controls or control set points to raise and lower temperature and humidity as necessary
- Shut off or isolate all nonessential equipment and spaces
- Lower thermostat set points in winter
- Raise chilled-water temperature
- Lower hot-water temperature (*Note*: Keep hot-water temperature higher than 145°F if a noncondensing gas boiler is used)
- Reduce or eliminate reheat and recool
- Reduce (and eliminate during unoccupied hours) mechanical ventilation and exhaust airflow
- Raise thermostat set points in summer or turn cooling equipment off

Lighting Systems

- Evaluate overlit areas and remove lamps or reduce lamp wattage
- Use task lighting where appropriate
- Move building functions to exterior or daylit areas
- Turn off electric lights in areas with adequate natural light
- Revise building cleaning and security procedures to minimize lighting periods
- Consolidate parking and turn off unused parking security lighting

Special Equipment

- Take transformers offline during periods of nonuse
- Shut off or regulate the use of vertical transportation systems

- Shut off unused or unnecessary equipment, such as photocopiers, music systems, and computers
- Reduce or turn off potable hot-water supply

Building Operation Demand Reduction

- Sequence or interlock heating or air-conditioning systems
- Disconnect or turn off all nonessential loads
- Reduce lighting levels
- Preheat or precool, if possible, before utility-imposed emergency periods

When Power Is Restored

- To prevent overloading the system, turn equipment back on gradually
- Test and verify proper operation of critical equipment, security, and fire and smoke alarms
- Check monitors on temperature-sensitive equipment
- Discuss lessons learned with staff and make any necessary changes to emergency plan
- Restock whatever emergency supplies were used, including alternative fuels

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ONLINE RESOURCES

ENERGY STAR financial evaluation tools: www.energystar.gov/index.cfm?c=assess_value.financial_tools
- Building upgrade value calculator
- Cash flow opportunity calculator
- Financial value calculator

End-use energy survey spreadsheet tool: www.focusonenergy.com/files/Document_Management_System/Business_Programs/equipmentusage_spreadsheet.xls

Building energy software tools directory: http://apps1.eere.energy.gov/buildings/tools_directory/

This directory provides information on almost 400 building software tools for evaluating energy efficiency, renewable energy, and sustainability in buildings. The energy tools listed in this directory include databases, spreadsheets, component and systems analyses, and whole-building energy performance simulation programs. A short description is provided for each tool along with other information, including expertise required, users, audience, input, output, computer platforms, programming language, strengths, weaknesses, technical contact, and availability.

2008 Buildings Energy Data Book (March 2009) on uses of energy in buildings: http://buildingsdatabook.eren.doe.gov/docs%5CDataBooks%5C2008_BEDB_Updated.pdf

U.S. Energy Information Administration's commercial buildings energy consumption survey (commercial energy uses and costs): www.eia.doe.gov/emeu/cbecs/

Emissions associated with energy generation (eGRID): www.epa.gov/cleanenergy/energy-resources/egrid/index.html

Climate zone information: http://resourcecenter.pnl.gov/cocoon/morf/ResourceCenter/article/1420