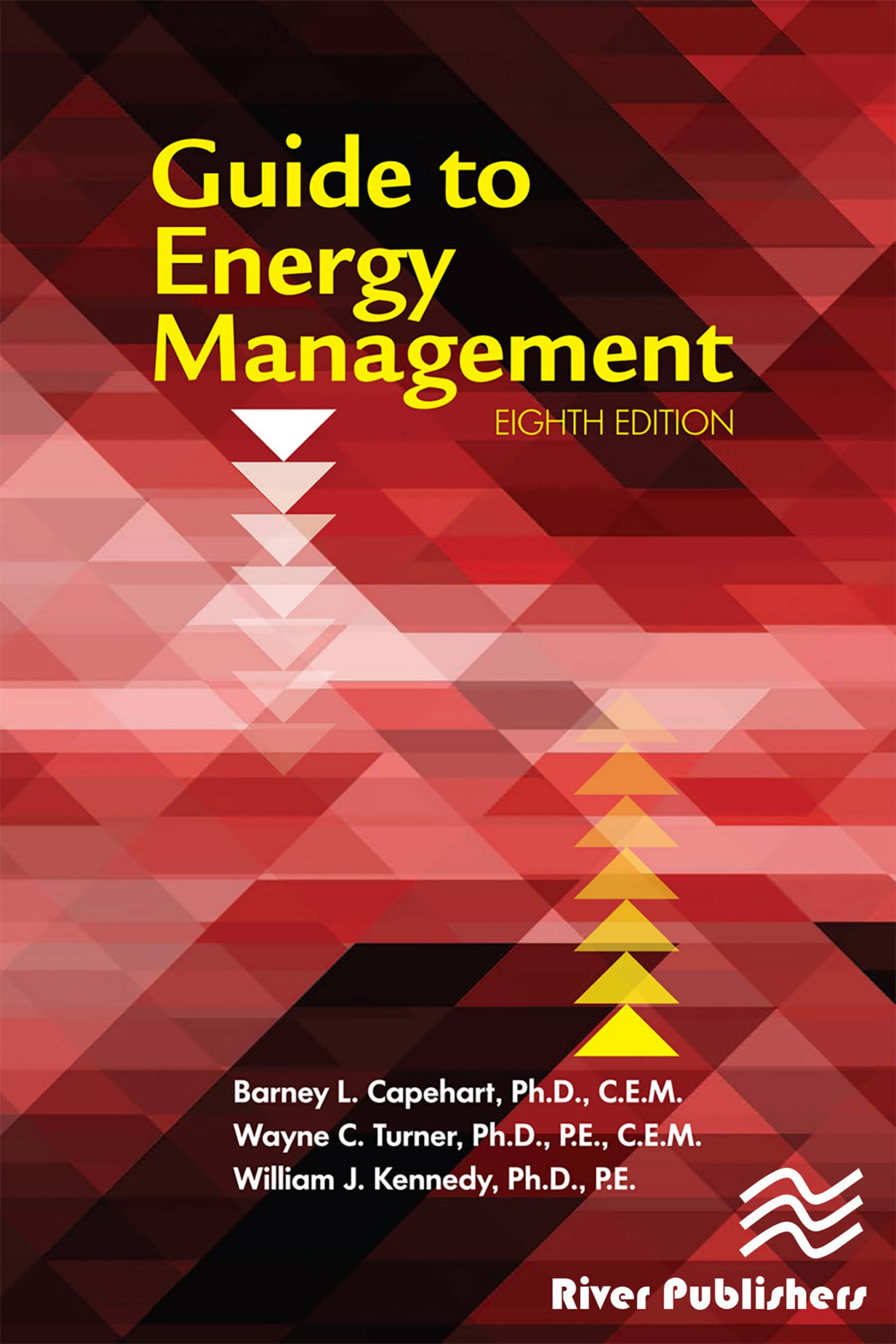

# Guide to Energy Management

EIGHTH EDITION

Barney L. Capehart, Ph.D., C.E.M.
Wayne C. Turner, Ph.D., P.E., C.E.M.
William J. Kennedy, Ph.D., P.E.

River Publishers

# Guide to Energy Management

Eighth Edition

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# Contents

# Preface to the Eighth Edition

The wild ride on the roller coaster of energy prices continues with the price of oil having soared to almost $150 a barrel in early 2008, and plunged to $35 a barrel in late 2008. In 2010, oil prices averaged about $80 a barrel. In 2014 oil was also about $80 a barrel, but dropped to $45 a barrel in August 2015. Some estimates of crude oil prices are as low as $30 a barrel in late 2015. In the spring of 2015, gasoline prices were about $2.50 a gallon, and both people and businesses are enjoying lower prices for a while. With significantly greater federal expenditures for energy efficiency and renewable energy over the last five years, our work as energy managers, facility managers, and other energy professionals has continued in high gear. Using our new opportunities for implementing more energy cost reduction projects, results have come in the form of huge cost savings for our companies and organizations. However, all of these past successes have not eliminated—or really even slowed—the continuing need to install new equipment, new technology and new processes to produce energy savings as well as help reduce pollution and improve quality and productivity. Energy managers and energy professionals are not going to work themselves out of a job!

One more reason that energy managers and energy professionals are not going to work themselves out of a job is that "the job" keeps changing. First it was just energy and energy cost, then it expanded to include water and sewer use and cost. Now our responsibilities have greatly expanded to include construction and operational aspects involving sustainability, green, LEED, Energy Star, renewable energy, and low carbon footprints. All of these new parts of our jobs are intimately related to our energy use, so we are the "usual suspects" to be asked to accomplish these tasks, too! Now we have a large set of additional drivers for our "old work" of making our facilities and operations more energy efficient and using more renewable energy. While this increases our work load and our need to learn new things, it also greatly expands our opportunities to find ways to make some of our "energy projects" far more cost effective. There will be many more win-win projects for us in the future.

The *Guide to Energy Management* continues as one of the leading educational resources for the person who is active as an energy manager or energy professional, as well as helping new people enter the fascinating and important field of energy management and energy engineering. *Guide to Energy Management* is the most widely used college and university textbook in this field, as well as one of the most widely used books for professional development training in the field. At the end of 2014 over 17,000 energy professionals had been trained using the first seven editions. In this eighth edition, we have added four new chapters with the extremely timely topics of electrical systems; motors and drives; commissioning (written by Wayne Robertson and Micheal Smith); and human behavior and facility energy management (written by Eric Mazzi, Kady Cowan, and Eileen Westervelt). We have also significantly updated two chapters on lighting, and on HVAC systems; and Paul Allen updated his chapter on web based building automation and control systems. Dr. Stephen Roosa updated his chapter on green buildings; and Dr. Eric Woodroof updated his chapter on green house gas management. And thanks to Mr. Klaus Pawlik for his help in coordinating the *Solutions Manual* with the problems contained in Appendix I of this book.

Thanks to the many energy professionals who have suggested improvements to this book, and have helped point out errors or inconsistencies. There is always room for improvement, so please let us know if you find any parts of the book needing improvement. We always appreciate hearing constructive criticism.

Good luck to all of you in your search for new, green, energy cost savings opportunities! And may we all be successful in providing an energy future for our country and our grandchildren that is efficient and sustainable.

*Barney L. Capehart*
*Wayne C. Turner*
*William J. Kennedy*
*August 2015*

# Chapter 1

# Introduction to Energy Management

## 1.0 ENERGY MANAGEMENT

The phrase energy management means different things to different people. To us, energy management is:

> The efficient and effective use of energy to maximize profits (minimize costs) and enhance competitive positions

This rather broad definition covers many operations from services to product and equipment design through product shipment. Waste minimization and disposal also presents many energy management opportunities. Our main focus in this book is energy management in buildings, manufacturing, and industry.

A whole systems viewpoint to energy management is required to ensure that many important activities will be examined and optimized. Presently, many businesses and industries are adopting a Total Quality Management (TQM) strategy for improving their operations. Any TQM approach should include an energy management component to reduce energy costs.

The primary objective of energy management is to maximize profits or minimize costs. Some desirable subobjectives of energy management programs include:

1. Improving energy efficiency and reducing energy use, thereby reducing costs

2. Reduce greenhouse gas emissions and improve air quality.

3. Cultivating good communications on energy matters

4. Developing and maintaining effective monitoring, reporting, and management strategies for wise energy usage
5. Finding new and better ways to increase returns from energy investments through research and development
6. Developing interest in and dedication to the energy management program from all employees
7. Reducing the impacts of curtailments, brownouts, or any interruption in energy supplies

Although this list is not exhaustive, these seven are sufficient for our purposes. However, the seventh objective requires a little more explanation.

Curtailments occur when a major supplier of an energy source is forced to reduce shipments or allocations (sometimes drastically) because of severe weather conditions and/or distribution problems. For example, natural gas is often sold to industry relatively inexpensively, but on an interruptible basis. That is, residential customers and others on noninterruptible schedules have priority, and those on interruptible schedules receive what is left. This residual supply is normally sufficient to meet industry needs, but periodically gas deliveries must be curtailed.

Even though curtailments do not occur frequently, the cost associated with them is so high—sometimes a complete shutdown is necessary—that management needs to be alert in order to minimize the negative effects. There are several ways of doing this, but the method most often employed is the storage and use of a secondary or standby fuel. Number 2 fuel oil is often stored on site and used in boilers capable of burning either natural gas (primary fuel) or fuel oil (secondary fuel). Then when curtailments are imposed, fuel oil can be used. Naturally, the cost of equipping boilers with dual fire capability is high, as is the cost of storing the fuel oil. However, these costs are often minuscule compared to the cost of forced shutdowns. Other methods of planning for curtailments include production scheduling to build up inventories, planned plant shutdowns, or vacations during curtailment-likely periods, and contingency plans whereby certain equipment, departments, etc., can be shut down so critical areas can keep operating. All these activities must be included in an energy management program.

Although energy conservation is certainly an important part of energy management, it is not the only consideration. Curtailment-contingency planning is certainly not conservation, and neither are load shedding or power factor improvement, both of which will be discussed later on in this book. To concentrate solely on conservation would preclude some of the most important activities—often those with the largest savings opportunity.

## 1.1 THE NEED FOR ENERGY MANAGEMENT

### 1.1.1 Economics

The American free enterprise system operates on the necessity of profits, or budget allocations in the case of nonprofit organizations. Thus, any new activity can be justified only if it is cost effective; that is, the net result must show a profit improvement or cost reduction greater than the cost of the activity. Energy management has proven time and time again that it is cost effective.

An energy cost savings of 5-15 percent is usually obtained quickly with little to no required capital expenditure when an aggressive energy management program is launched. An eventual savings of 30 percent is common, and savings of 50, 60, and even 70 percent have been obtained. These savings all result from retrofit activities. New buildings designed to be energy efficient can operate on 20 percent of the energy (with a corresponding 80 percent savings) normally required by existing buildings. In fact, for most manufacturing, industrial, and other commercial organizations *energy management is one of the most promising profit improvement-cost reduction programs available today.*

### 1.1.2 National Good

Energy management programs are vitally needed today. One important reason is that energy management helps the nation face some of its biggest problems. The following statistics will help make this point.*

- Growth in U.S. energy use:
  It took 50 years (1900-1950) for total annual U.S. energy consumption to go from 4 million barrels of oil equivalent (MBOE) per day to 16 MBOE. It took only 20 years (1950-1970) to go from 16 to 32 MBOE. This rapid growth in energy use slowed in the early 1970's, but took a spurt in the late 1970's, reaching 40 MBOE in 1979. Energy use slowed again in the early 1980's and dropped to about 37 MBOE in 1983. Economic growth in the mid 1980's returned the use to 40 MBOE in 1987. Energy use remained fairly steady at just over 42 MBOE in the late 1980's, but started growing in the 1990s. By the end of 1994, energy use was up to almost 45 MBOE, and in 2004, just under 50 MBOE per day. Energy use

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*These statistics come from numerous sources, mostly government publications from the Energy Information Administration or from the U.S. Statistical Abstract.

remained around 50 MBOE per day for 2005 and 2006. After that, the world-wide economic slowdown dropped energy use to 47 MBOE in 2009. For 2010, this increased to 49 MBOE, per day; and for 2014, 48.5 MBOE.

- Comparison with other countries:
  With only 4.4 percent of the world's population, the United States consumes about 18 percent of its energy and produces about 22 percent of the world's gross national product (GNP). However, some nations such as Japan and Germany produce the same or greater GNP per capita with significantly less energy than the United States.

- U.S. energy production:
  Domestic crude oil production peaked in 1970 at just under 10 million barrels per day (MBD), and has fallen slowly since then to about 5.6 MBD in 2006, and 5.3 MBD in 2009. For 2010, this increased to about 5.85 MBD; and then in 2014 with fracking, new oil production was 9.2 MBD. Most likely in several more years, US oil production with be greater than 10 MBD. Domestic gas production peaked in 1973 at just over 21.7 trillion cubic feet (TCF) per year. Gas production slowly declined until 1987 when it fell to 16.1 TCF. Since 1988, gas production increased very slowly, and in 2003 was 19.7 TCF, and in 2006 it was 19.1. Deregulation has improved our domestic production. Since 1988, gas imports have been over 1 TCF per year, and have been increasing rapidly. In 2006, we imported over 4 TCF of natural gas.

  In 2009, net U.S. imports of natural gas were the lowest since 1994, representing just 12 percent of total consumption. The primary underlying cause for the lower level of net imports was continued strong levels of natural gas production in the lower 48 states. Dry natural gas production increased 3.3 percent compared with 2008 and was nearly 9 percent higher than in 2007. With these recent gains in domestic production, the United States is now the largest producer of natural gas in the world. U.S. domestic consumption decreased in 2009, which in turn contributed to a reduced demand for imports. Although liquefied natural gas (LNG) gross imports increased almost 30 percent (from a 5-year low established in 2008), LNG remains a very small source of supplies for the United States, accounting for less than 2 percent of consumption.

  In 2010, the domestic production of natural gas reached 22.1 TCF due to expanded shale gas production; and in 2014 it had increased to 27.3 TCF. Natural gas imports were down slightly to 3.78 TCF in 2010, and were 2.7 TCF in 2014.

- Cost of imported oil:
  Annual average prices per barrel for imported crude oil rapidly escalated from \$3.00 in the early 1970's to \$12 in 1973-1974 and to \$36 in 1981. After 1981, prices dropped to about \$12 in 1986. From 1986 to 1999, prices ranged from about \$12 to \$20 a barrel, with a short spike in prices during the 1989-90 Gulf War. Prices dropped to \$10 in 1998, and rose back to about \$26 in 2003. The 2004 cost was about \$24, but in early 2005, spot prices shot up to \$58 a barrel. In 2006 prices averaged around \$60 a barrel, and in 2007 spot prices for oil reached almost \$100 a barrel. In 2008 spot prices for oil spiked to almost \$150 a barrel before crashing back to \$35 a barrel later in the year. For 2009 the average cost for oil was almost \$60 per barrel. For 2010, the average cost of oil was about \$80 per barrel. With more oil production in the US from shale oil, US oil import was only 5.2 MBD in 2014, and crude oil prices dropped to \$55 per barrel for a period of time in early 2015.
- Reliance on imported oil:
  The United States has been a net importer of oil since 1947. In 1970 the bill for this importation was only \$3 billion; by 1977 it was \$42 billion; by 1979, \$57 billion; and by 1980, almost \$80 billion. This imported oil bill has severely damaged our trade balance and weakened the dollar in international markets. In 1986 the bill for oil imports fell to a low of \$35 billion. It climbed to almost \$62 billion in 1990. In 1996 it was just over \$72 billion, and with lower prices after 1996, it was just over \$50 billion in 1998. But, with higher prices starting in 2000, it was \$119 billion in 2000, \$132 billion in 2003, and \$179 billion in 2004. With the higher prices in 2005 and 2006, the total was \$300 billion in 2006! The cost continued to rise to over \$350 billion in 2008, but then dropped to less than \$200 billion in 2009 with the U.S. and global recession significantly reducing the use and cost of oil. In 2010, our cost of imported oil jumped 33% to \$251 billion.

In addition to these discouraging statistics, there are a host of major environmental problems, as well as economic and industrial competitiveness problems, that have come to the forefront of public concern. Reducing energy use can help minimize these problems by:

- <u>Reducing acid rain</u>. Acid rain has been reduced mainly through national and regional environmental policies around the world. The United States adopted the Clean Air Act Amendments of 1990, and the Clear Skies Act of 2003 which established a new trade program for sulfur oxides and nitrous oxides and mercury emissions from power plants. Canada has worked closely with the United States on acid rain reduction. The EU has adopted several policies related to the reduction of acid rain. The Asian development Bank has worked closely with China to help it make significant reductions in its potential for acid rain.

- <u>Limiting global climate change</u>. Carbon dioxide, the main contributor to potential global climate change, is produced by the combustion of fossil fuel, primarily to provide transportation and energy services. In 1992, many countries of the world adopted limitations on carbon dioxide emissions. Reducing fossil energy use through energy efficiency improvements and the use of renewable energy is without doubt the quickest, most effective, and most cost-effective manner for reducing greenhouse gas emissions, as well as improving air quality, in particular in densely populated areas.

  The first international treaty to address climate change was the United Nations Framework Convention on Climate Change (UNFCCC), which entered into force in 1994 and has been ratified by 186 countries, including the United States. Delegates to the UNFCCC then met in Kyoto, Japan, in 1997 to adopt a more significant treaty calling for binding targets and timetables, eventually agreeing on the Kyoto Protocol (KP). Delegates rejected language requiring participation by developing countries, thus damping U.S. enthusiasm. Nevertheless, the Kyoto Protocol entered into force in 2005, having been ratified by EU countries, Canada, Japan, Russia, and most developing countries. The United States and Australia are currently not parties to the KP.

  The U.S. considered legislation to control carbon emissions with a cap and trade approach in 2009 and 2010, but no formal control was approved. Currently, this legislation appears very unlikely to be approved anytime in the near future.

- <u>Reducing ozone depletion</u>. The Montréal Protocol of 1987, and its subsequent updates, is one of the most successful environmental protection agreements in the world. The Protocol sets out a mandatory timetable for the phase out of ozone depleting substances. This timetable has been under constant revision, with phaseout dates accelerated in accordance with scientific understanding and technological advances. Chlorofluorocarbon (CFC) production by developed countries was phased out at the end of 1995. Starting in 1996, hydrochlorofluorocarbons (HCFCs) began to be phased out by developed countries with a 65% reduction by 2010, and complete phase out by 2020.

- Improving national security. Oil imports directly affect the energy security and balance of payments of our country. These oil imports must be reduced for a secure future, both politically and economically. In 1973 our net imports were 34.8% of our use. In 1977 they were 46.5%, and in 1998 hit 50%. The percentage of our oil use that is imported continues to climb—56.1% in 2003, 57.8% in 2004, and 59.5% in 2006. In 2009, import levels reached almost 63%. Data for 2014 show a 27% level of oil imports—the lowest since 1985.

- Improving U.S. competitiveness. The U.S. spends about 9 percent of its gross national product for energy—a higher percentage than many of its foreign competitors. This higher energy cost amounts to a surtax on U.S. goods and services.

- Helping other countries. The fall of the Berlin Wall in 1989 and the emergence of market economies in most Eastern European countries have led to major changes in world energy supplies and demands. These changes significantly affect our nation, and provide us an economic impetus to help these countries greatly improve their own energy efficiencies and reduce their energy bills.

There are no easy answers. Each of the possibilities discussed below has its own problems.

- Many look to coal as the answer. Yet coal burning produces sulfur dioxide, and carbon dioxide which produce acid rain and potential global climate change. Research and development on "clean coal" technology is currently underway.

- Synfuels require strip mining, incur large costs, and place large demands for water in arid areas. On-site coal gasification plants associated with gas-fired, combined-cycle power plants are presently being demonstrated by several electric utilities. However, it remains to be seen if these units can be built and operated in a cost-effective and environmentally acceptable manner.

- Solar-generated electricity, whether generated through photovoltaics or thermal processes, is still more expensive than conventional sources and has large land requirements. Technological improvements are occurring in both these areas, and costs are decreasing. Sometime in the near future, these approaches may become cost-effective, with the current cost of large-scale solar PV generation under $4000 per kW in 2010. and under $1500 per kW in 2015.

- Biomass energy is also expensive, and any sort of monoculture would require large amounts of land. Some fear total devastation of forests. At best, biomass can provide only a few percentage points of our total needs without large problems.

- Wind energy is only feasible in limited geographical areas where the wind velocity is consistently high, and there are also some noise and aesthetic problems. However, the cost of wind generation systems has come down to $1000-$2000 per kW, and they are cost-effective in windy areas of the U.S. Operating costs are very low, and with new wind turbine technologies, large wind farms are being constructed in the midwest, southwest, and western regions of the U.S.

- Fuel cells and their ability to cleanly produce electricity from hydrogen and oxygen are what make them and hydrogen attractive. However, hydrogen is not a primary source of energy. It is made from other forms of energy; most hydrogen production today is by steam reforming natural gas. Natural gas is a fossil fuel, so the carbon dioxide released in the reformation process adds to the greenhouse effect. Only when hydrogen is made cost effectively from renewable energy sources does it have any significant value as a fuel source for a fuel cell. Then fuel cells will be of great interest and use. 2010 prices for fuel cells were around $4500 per kW.

- Alcohol production from agricultural products raises perplexing questions about using food products for energy when large parts of the world are starving. Newer processes for producing alcohol from wood waste are still being tested, and may offer some significant improvements in this limitation. In the meantime, quite a few new ethanol plants are being started up to produce this alternate energy fuel. Brazil has a very large and successful ethanol production industry from sugar cane.

- Fission has the well-known problems of waste disposal, safety, and a short time span with existing technology. Without breeder reactors or nuclear fuel reprocessing, we will soon run out of fuel, but breeder reactors dramatically increase the production of plutonium—a raw material for nuclear bombs. Nuclear fuel reprocessing could provide many years of fuel by recycling partially used fuel now being kept in storage. Newer reactor designs appear to be safer and porentially cheaper.

- Fusion seems to be everyone’s hope for the future, but many claim that we do not know the area well enough yet to predict its problems.

When available commercially, fusion may very well have its own style of environmental-economical problems.

The preceding discussion paints a rather bleak picture. Our nation and our world are facing severe energy problems and there appears to be no simple answers.

Time and again energy management has shown that it can substantially reduce energy costs and energy consumption through improved energy efficiencies. This saved energy can be used elsewhere, so one energy source not mentioned in the preceding list is energy management. In fact, energy available from energy management activities has almost always proven to be the most economical source of "new" energy. Furthermore, energy management activities are more gentle to the environment than large-scale energy production, and they certainly lead to less consumption of scarce and valuable resources. Thus, although energy management cannot solve all the nation's problems, *perhaps it can ease the strain on our environment and give us time to develop new energy sources.*

The value of energy management is clear. There is an increased need for engineers who are adequately trained in the field of energy manage-

**Table 1-1**
**Energy Units and Energy Content of Fuels**

| | |
|---|---|
| 1 kWh | 3412 Btu |
| 1 $ft^3$ natural gas | 1000 Btu |
| 1 Ccf natural gas | 100 $ft^3$ natural gas |
| 1 Mcf natural gas | 1000 $ft^3$ natural gas |
| 1 therm | 100,000 Btu |
| 1 barrel crude oil | 5,100,000 Btu |
| 1 ton coal | 25,000,000 Btu |
| 1 gallon gasoline | 125,000 Btu |
| 1 gallon #2 fuel oil | 140,000 Btu |
| 1 gallon LP gas | 95,000 Btu |
| 1 cord of wood | 30,000,000 Btu |
| 1 MBtu | 1000 Btu |
| 1 MMBtu | $10^6$ Btu |
| 1 Quad | $10^{15}$ Btu |
| 1 MW | $10^6$ watts |

ment, and a large number of energy management jobs are available. This text will help you prepare for a career which will be both exciting and challenging.

## 1.2 ENERGY BASICS FOR ENERGY MANAGERS

An energy manager must be familiar with energy terminology and units of measure. Different energy types are measured in different units. Knowing how to convert from one measurement system to another is essential for making valid comparisons. The energy manager must also be informed about the national energy picture. The historical use patterns as well as the current trends are important to an understanding of options available to many facilities.

### 1.2.1 Energy Terminology, Units and Conversions

Knowing the terminology of energy use and the units of measure is essential to developing a strong energy management background. Energy represents the ability to do work, and the standard engineering measure for energy used in this book is the British thermal unit, or Btu. One Btu is the amount of energy needed to raise the temperature of one pound of water one degree Fahrenheit. In more concrete terms, one Btu is the energy released by burning one kitchen match head, according to the U.S. Energy Information Agency. The energy content of most common fuels is well known, and can be found in many reference handbooks. For example, a gallon of gasoline contains about 125,000 Btu and a barrel of oil contains about 5,100,000 Btu. A short listing of the average energy contained in a number of the most common fuels, as well as some energy unit conversions is shown below in Table 1-1.

Electrical energy is also measured by its ability to do work. The traditional unit of measure of electrical energy is the kilowatt-hour; in terms of Btu's, one kilowatt-hour (kWh) is equivalent to 3412 Btu. However, when electrical energy is generated from steam turbines with boilers fired by fossil fuels such as coal, oil or gas, the large thermal losses in the process mean that it takes about 10,000 Btu of primary fuel to produce one kWh of electrical energy. Further losses occur when this electrical energy is then transmitted to its point of ultimate use. Thus, although the electrical energy at its point of end-use always contains 3412 Btu per kWh, it takes considerably more than 3412 Btus of fuel to produce a kWh of electrical energy.

### 1.2.2 Energy Supply and Use Statistics

See new numbers for US Energy Supply and Energy Use for 2014.

### 1.2.3 Energy Use in Commercial Businesses

One question frequently asked by facility energy managers is "How does energy use at my facility compare to other facilities in general, and to other facilities that are engaged in the same type of operation?" Figure 1-3 shows general energy usage in commercial facilities, and Figure 1-4 shows their electricity use. While individual facilities may differ significantly from these averages, it is still helpful to know what activities are likely to consume the most energy. This provides some basis for a comparison to other facilities—both energy wasting and energy efficient. In terms of priority of action for an energy management program, the largest areas of energy consumption should be examined first. The greatest savings will almost always occur from examining and improving the areas of greatest use.

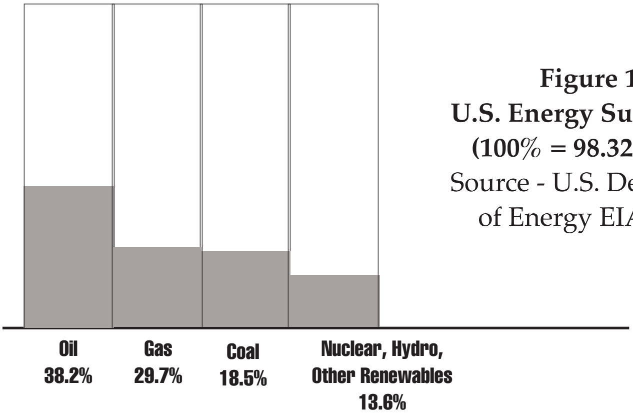

**Figure 1-1**
**U.S. Energy Supply 2014**
**(100% = 98.32 Quads)**
Source - U.S. Department of Energy EIA (2014)

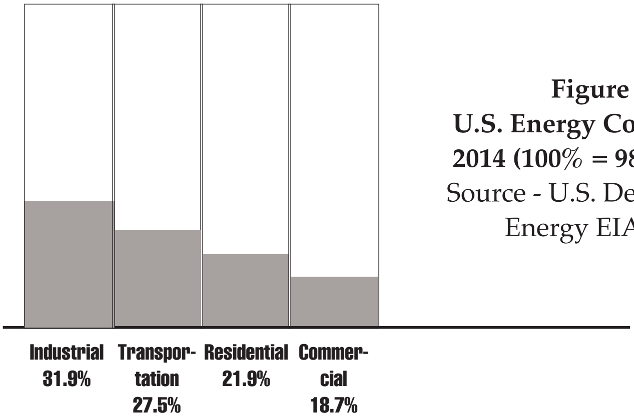

**Figure 1-2**
**U.S. Energy Consumption 2014 (100% = 98.32 Quads)**
Source - U.S. Department of Energy EIA (2014)

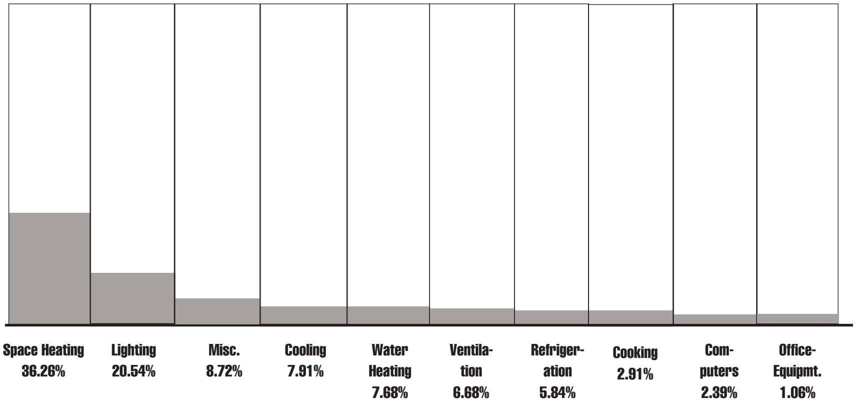

**Figure 1-3**

**Commercial Energy Use 2003 (end-use basis) for all Commercial Buildings**

Source - U.S. Department of Energy EIA (2011)

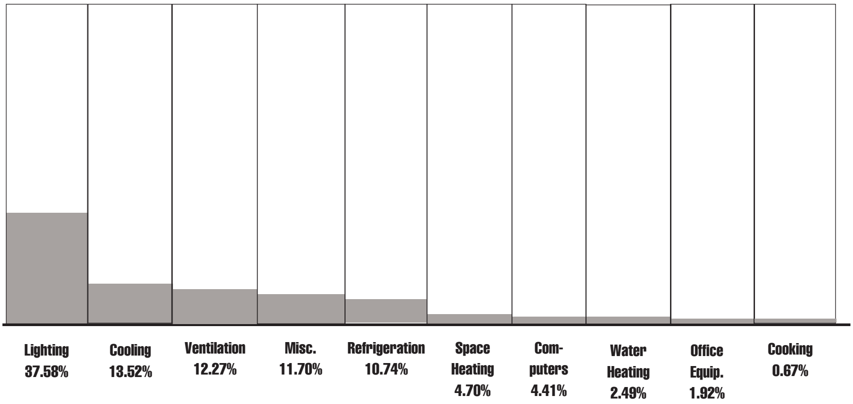

**Figure 1-4.Commercial Electric Use 1999 (end-use basis)**

Source - U.S. Department of Energy EIA (2011)

The commercial sector uses about 19 percent of all the primary energy consumed in the United States, at a cost of over $192 billion in 2008 [1]. On an end-use basis, natural gas, oil and district heating constitute about 45.4 percent of the commercial energy use, mainly for space heating. Over 64 percent of the energy use is in the form of electricity for lighting, air conditioning, and ventilation. Electricity provides over half of the end-use energy used by a commercial facility, but it represents about two thirds of the cost of the energy needed to operate the facility. Lighting is the predominant use of electricity in commercial buildings, and accounts for over one-third of the cost of electricity.

Commercial activity is very diverse, and this leads to greatly varying energy intensities depending on the nature of the commercial facility. Recording energy use in a building or a facility of any kind and providing a history of this use is necessary for the successful implementation of an energy management program. A time record of energy use allows analysis and comparison so that results of energy productivity programs can be determined and evaluated.

### 1.2.4 Energy Use in Industry

The industrial sector—consisting of manufacturing, mining, agriculture and construction activities—consumes almost 31% of the nation's primary energy use, at an annual cost of over $206 billion in 2008 [2]. Industrial energy use is shown in Figure 1-5 and industrial electricity use is shown in Figure 1-6.

Manufacturing companies, which use mechanical or chemical processes to transform materials or substances into new products, account for about 85 percent of the total industrial sector use. The "big three" in energy use are chemicals, petroleum, and pulp and paper; these industries together consume over one-half of all industrial energy. The "big five," which add the primary metals industry, as well as the food and kindred products group, together account for 70 percent of all industrial sector energy consumption.

According to the U.S. Energy Information Administration, energy efficiency in the manufacturing sector improved by 25 percent over the period 1980 to 1985 [3]. During that time, manufacturing energy use declined 19 percent, and output increased 8 percent. These changes resulted in an

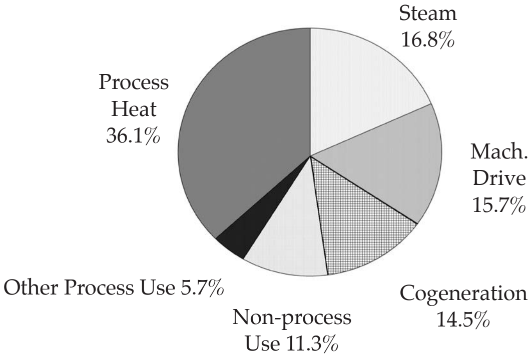

**Figure 1-5**
**Industrial Energy Use 2002 (end-use basis)**
Source - U.S. Department of Energy EIA (2005)

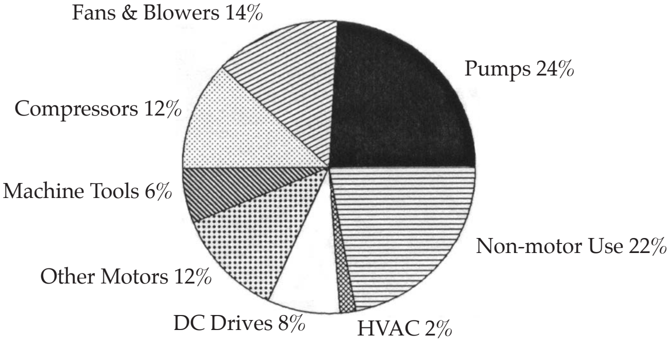

**Figure 1-6**
**Industrial Electricity Use (end-use basis)**
Source - Federal Energy Management Agency

overall improvement in energy efficiency of 25 percent. However, the "big five" did not match this overall improvement; although their energy use declined 21 percent, their output decreased by 5 percent—resulting in only a 17 percent improvement in energy efficiency during 1980-1985. This overall five-year record of reduction in energy use of the manufacturing sector came to an end in 1986, with total energy use in the sector growing by 10 percent from 1986 to 1988. Manufacturing energy use has continued to grow at a slower rate since 1988, but industrial output has grown at a faster rate [9]. Use of new energy efficient technology, and the changing production mix from the manufacture of energy-intensive products to less intensive products has accounted for much of this difference.

Between 1985 and 2004, industrial energy intensity, based on energy used per unit of gross domestic product, dropped almost 20%. These data came from the Energy Efficiency and Renewable Energy Office of the U.S. Department of Energy. In addition, some data have become available on the energy use intensity for two subsectors of the primary metals category. These data are for the energy used to produce $2000 of shipped product value in 1998, 2002, and 2006.

**Intensity of Fuel Use, Btu per 2000 Dollar Value of Shipment**

| | 1998 | 2002 | 2006 |
|---|---|---|---|
| Alumina and Aluminum | 13,065 | 11,418 | 8,342 |
| Iron and Steel Mills | 32,177 | 30,176 | 18,468 |

Sources: EIA, Manufacturing Energy Consumption Surveys, U.S. Department of Commerce, Bureau of Economic Analysis, Value of Shipments and Price Indexes by Detailed Industry (1998-2006)

The energy used to produce $2000 of alumina and aluminum dropped 36% from 1998 to 2006, and the energy used to produce $2000 of products from iron and steel mills dropped 43% in that same time period.

Continuing this record of energy efficiency improvements in manufacturing will require both re-establishing emphasis on energy management and making capital investments in new plant processes and facilities improvements. Reducing our energy costs per unit of manufactured product is one way that our country can become more competitive in the global industrial market. It is interesting to note that Japan—one of our major industrial competitors—has a law that every industrial plant must have a full-time energy manager [4].

## 1.3 DESIGNING AN ENERGY MANAGEMENT PROGRAM

### 1.3.1 Management Commitment

The most important single ingredient for successful implementation and operation of an energy management program is commitment to the program by top management. Without this commitment, the program will likely fail to reach its objectives. Thus, the role of the energy manager is crucial in ensuring that management is committed to the program.

Two situations are likely to occur with equal probability when designing an energy management program. In the first, management has decided that energy management is necessary and wants a program implemented. This puts you—the energy manager—in the *response* mode. In the second, you—an employee—have decided to convince management of the need for the program so you are in the aggressive mode. Obviously, the most desirable situation is the response mode as much of your sales effort is unnecessary; nonetheless, a large number of energy management programs have been started through the *aggressive* mode. Let's consider each of these modes.

In a typical scenario of the response mode, management has seen rapidly rising energy prices and/or curtailments, has heard of the results of other energy management programs, and has then initiated action to start the program. In this case, the management commitment already exists, and all that needs to be done is to cultivate that commitment periodically and to be sure the commitment is evident to all people affected by the program. We will discuss this aspect more when we talk about demonstrating the commitment.

In the aggressive mode, you, the employee, know that energy costs are rising dramatically and that sources are less secure. You may have taken a course in energy management, attended professional conferences, and/or read papers on the subject. At any rate, you are now convinced that the company needs an energy management program. All that remains is to convince management and obtain their commitment.

The best way to convince management is with facts and statistics. Sometimes the most startling way to show the facts is through graphs such as Figure 1-7. Note that different goals of energy cost reduction are shown. This graph can be done in total for all energy sources, or several graphs can be used—one for each source. The latter is probably better as savings goals can be identified by energy source. You must have accurate data. Past figures can use actual utility bills, but future figures call for forecasting. Local utilities and various state energy agencies can help you provide management with more accurate data.

Follow this data with quotes on programs from other companies showing these goals are realistic. Other company experiences are widely published in the literature; results can also be obtained through direct contacts with the energy manager in each company. Typical cost avoidance figures are shown in Table 1-2. However, as time progresses and the technology matures, these figures tend to change. For example, a short time ago only a few people believed that an office building could reduce

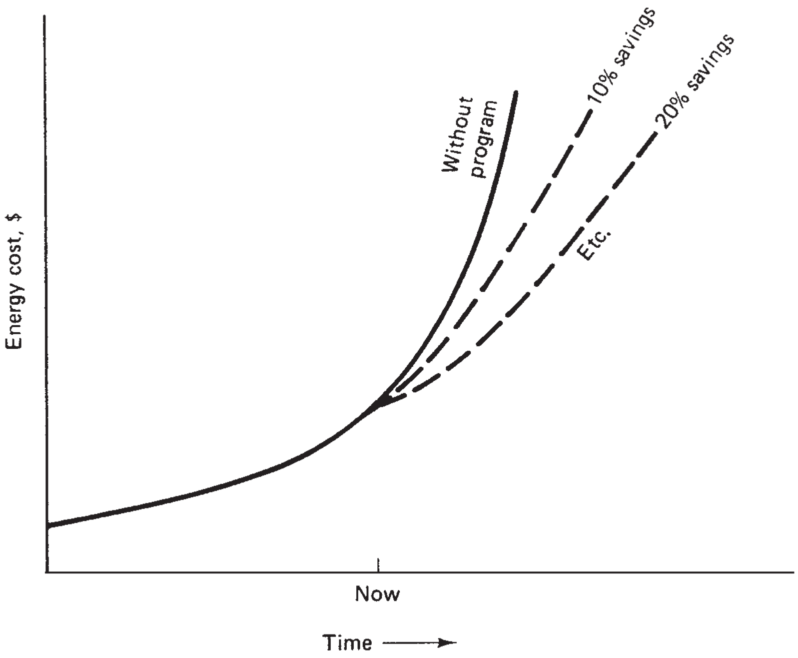

Figure 1-7. Energy Costs—Past and Future.

energy consumption by 70 percent or that manufacturing plants could operate on half the energy previously required, yet both are now occurring on a regular basis.

**Table 1-2**
**Typical Energy Savings**

| | |
|---|---|
| Low cost, no cost changes | 5-10% |
| Dedicated programs (3 years or so) | 25-35% |
| Long-range goal | 40-50% |

As the proponent of an energy management program, you could then talk about the likelihood of energy curtailments or brownouts and what they would mean to the company. Follow this with a discussion of what the energy management program can do to minimize the impacts of curtailments and brownouts.

Finally, your presentation should discuss the competition and what they are doing. Accurate statistics on this can be obtained from trade and professional organizations as well as the U.S. Department of Energy. The savings obtained by competitors can also be used in developing the goals for your facility.

### 1.3.2 Energy Management Coordinator/Energy Manager

To develop and maintain vitality for the energy management program, a company must designate a single person who has responsibility for coordinating the program. If no one person has energy management as a specific part of his or her job assignment, management is likely to find that the energy management efforts are given a lower priority than other job responsibilities. Consequently, little or nothing may get done.

The energy management coordinator (EMC) should be strong, dynamic, goal oriented, and a good manager. Most important, management should support that person with resources including a staff. The energy management coordinator should report as high as possible in the organization without losing line orientation. A multiplant or multidivisional corporation may need several such coordinators—one for each plant and one for each level of organization. Typical scenarios are illustrated in Figure 1-8.

### 1.3.3 Backup Talent

Unfortunately, not all the talent necessary for a successful program resides in one person or discipline. For example, several engineering disci-

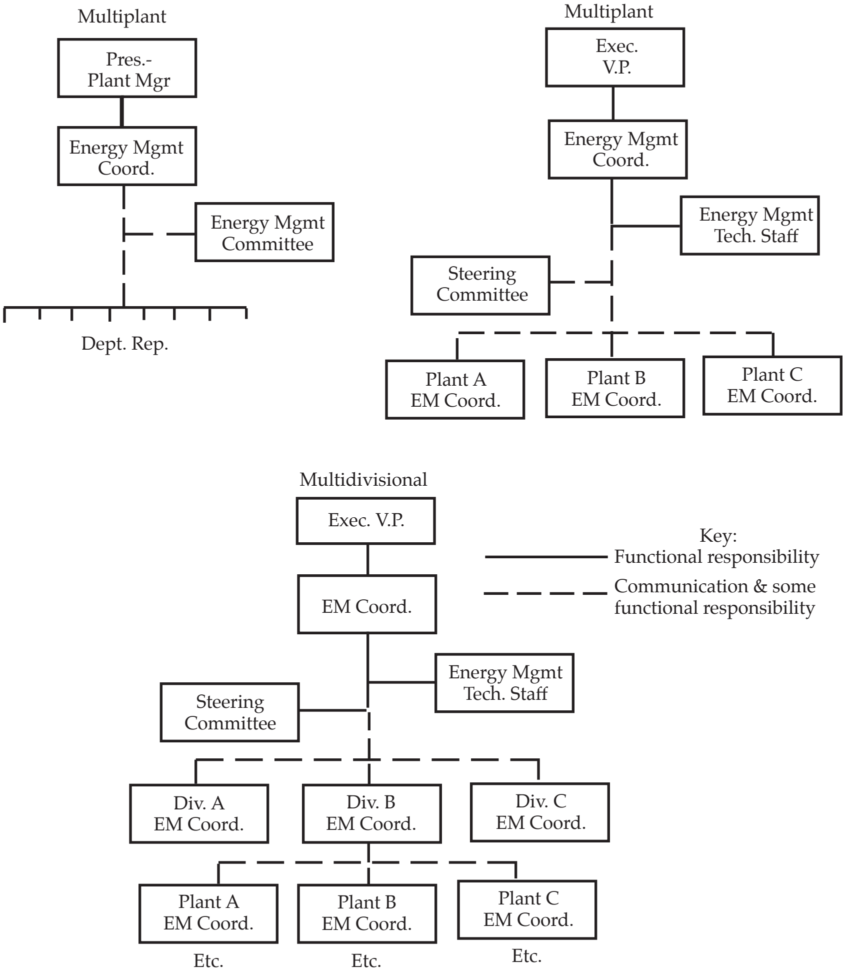

**Figure 1-8**
**Typical Organization Designs for Energy Management Programs**

plines may be necessary to accomplish a full-scale study of the plant steam production, distribution, usage, and condensate return system. For this reason, most successful energy management programs have an energy management committee. Two subcommittees that are often desirable are the technical and steering subcommittees.

The technical committee is usually composed of several persons with strong technical background in their discipline. Chemical, industrial, electrical, civil, and mechanical engineers as well as others may all be represented on this committee. Their responsibility is to provide technical assistance for the coordinator and plant-level people. For example, the committee can keep up with developing technology and research into po-tential applications company-wide. The results can then be filtered down.

While the energy management coordinator may be a full-time position, the technical committee is likely to operate part-time, being called upon as necessary. In a multiplant or multidivisional organization, the technical committee may also be full time.

The steering committee has an entirely different purpose from the technical committee. It helps guide the activities of the energy management program and aids in communications through all organizational levels. The steering committee also helps ensure that all plant personnel are aware of the program. The steering committee members are usually chosen so that all major areas of the company are represented. A typical organization is presented in Figure 1-9.

Steering committee members should be selected because of their widespread interests and a sincere desire to aid in solving the energy problems. Departmental and hourly representatives can be chosen on a rotating basis. Such a committee should be able to develop a good composite picture of plant energy consumption which will help the energy management coordinator choose and manage his/her activities.

### 1.3.4 Cost Allocation

One of the most difficult problems for the energy manager is to try to reduce energy costs for a facility when the energy costs are accounted for as part of the general overhead. In that case, the individual managers and supervisors do not consider themselves responsible for controlling the energy costs. This is because they do not see any direct benefit from reducing costs that are part of the total company overhead. The best solution to this problem is for top management to allocate energy costs down to "cost centers" in the company or facility. Once energy costs are charged to production centers in the same way that materials and labor

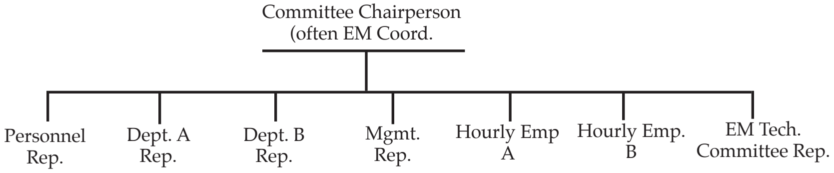

**Figure 1-9**
**Energy Management Steering Committee.**

are charged, then the managers have a direct incentive to control those energy costs because this will improve the overall cost-effectiveness of the production center.

For a building, this allocation of energy costs means that each of the tenants are given information on their energy consumption, and that they individually pay for that energy consumption. Even if a large building is "master metered" to reduce utility fixed charges, there should be a division of the utility cost down to the individual customers.

### 1.3.5 Reporting and Monitoring

It is critical for the energy management coordinator and the steering committee to have their fingers on the "pulse of energy consumption" in the plant. This is best achieved through an effective and efficient system of energy reporting.

The objective of an energy reporting system is to measure energy consumption and compare it either to company goals or to some *standard of energy consumption.* Ideally, this should be done for each operation or production cost center in the plant, but most facilities simply do not have the required metering devices. Many plants only meter energy consumption at one place—where the various sources enter the plant. Most plants are attempting to remedy this, however, by installing additional metering devices when the opportunity arises (steam system shutdowns, vacation downtime, etc.). Systems that should be metered include steam, compressed air, and chilled and hot water.

As always, the reporting scheme needs to be reviewed periodically to ensure that only necessary material is being generated, that all needed data is available, and that the system is efficient and effective. For a more complete description of this method and its applications, see section 1.7 on Energy Monitoring, Targeting and Reporting.

### 1.3.6 Training

Most energy management coordinators find that substantial training is necessary. This training can be broken down as shown in Figure 1-10.

Training cannot be accomplished overnight, nor is it ever "completed." Changes occur in energy management staff and employees at all levels, as well as new technology and production methods. All these precipitate training or retraining. The energy management coordinator must assume responsibility for this training.

| *Personnel involved* | *Type of necessary training* | *Source of required training* |
|---|---|---|
| 1. Technical committee | 1. Sensitivity to EM | 1. In house (with outside help ?) |
| | 2. Technology developments | 2. Professional societies universities, consulting groups, journals |
| 2. Steering committee | 1. Sensitivity to EM | 1. See 1 above |
| | 2. Other Industries' experience | 2. Trade journals, energy sharing groups, consultants |
| 3. Plant-wide | 1. Sensitivity to EM | 1. In house |
| | 2. What's expected, goals to be obtained, etc. | 2. In house |

**Figure 1-10**
**Energy Management Training**

## 1.4 STARTING AN ENERGY MANAGEMENT PROGRAM

Several items contribute to the successful start of an energy management program. They include:

1. Visibility of the program start-up
2. Demonstration of management commitment to the program
3. Selection of a good initial energy management project

### 1.4.1 Visibility of Start-up

To be successful, an energy management program must have the backing of the people involved. Obtaining this support is often not an easy task, so careful planning is necessary. The people must:

1. Understand why the program exists and what its goals are;
2. See how the program will affect their jobs and income;
3. Know that the program has full management support; and
4. Know what is expected of them.

Communicating this information to the employees is a joint task of management and the energy management coordinator. The company must take advantage of all existing communications channels while also taking into consideration the preceding four points. Some methods that have proven useful in most companies include:

- Memos. Memos announcing the program can be sent to all employees. A comprehensive memo giving fairly complete details of the program can be sent to all management personnel from first-line supervision up. A more succinct one can be sent to all other employees that briefly states why the program is being formed and what is expected of them. These memos should be signed by local top management.

- News releases. Considerable publicity often accompanies the program start-up. Radio, TV, posters, newspapers, and billboards can all be used. The objective here is to obtain as much visibility for the program as possible and to reap any favorable public relations that might be available. News releases should contain information of interest to the general public as well as employees.

- Meetings. Corporate, plant, and department meetings are sometimes used, in conjunction with or in lieu of memos, to announce the program and provide details. Top management can demonstrate commitment by attending these meetings. The meeting agenda must provide time for discussion and interaction.

- Films, video tapes. Whether produced in-house or purchased, films and video tapes can add another dimension to the presentation. They can also be reused later for new employee training.

### 1.4.2 Demonstration of Management Commitment

As stressed earlier, management commitment to the program is essential, and this commitment must be obvious to all employees if the program is to reach its full potential. Management participation in the program start-up demonstrates this commitment, but it should also be emphasized in other ways. For example:

- Reward participating individuals. Recognition is highly motivating for most employees. An employee who has been a staunch supporter of the program should be recognized by a “pat on the back,” a letter in the files, acknowledgment at performance appraisal time, etc. When the employee has made a suggestion that led to large energy savings, his/her activities should be recognized through monetary rewards, publicity, or both. Public recognition can be given in the company newsletter, on bulletin boards, or in plant-department meetings.

- Reinforce commitment. Management must realize that they are continually watched by employees. Lip service to the program is not enough—personal commitment must be demonstrated. Management should reinforce its commitment periodically, although the visibility scale can be lower than before. Existing newsletters, or a separate one for the energy management program, can include a short column or letter from management on the current results of the program and the plans for the future. This same newsletter can report on outstanding suggestions from employees.

- Fund cost-effective proposals. All companies have capital budgeting problems in varying degrees of severity, and unfortunately energy projects do not receive the same priority as front-line items such as equipment acquisition. However, management must realize that turning down the proposals of the energy management team while accepting others with less economic attractiveness is a sure way to kill enthusiasm. Energy management projects need to compete with others fairly. If an energy management project is cost effective, it should be funded. If money is not available for capital expenditures, then management should make this clear at the outset of the program and ask the team to develop a program which does not require capital expenditures.

### 1.4.3 Early Project Selection

The energy management program is on treacherous footing in the beginning. Most employees are afraid their heat is going to be set back, their air conditioning turned off, and their lighting reduced. If any of these actions do occur, it's little wonder employee support wanes. These things might occur eventually, but wouldn't it be smarter to have less controversial actions as the early projects.

An early failure can also be harmful, if not disastrous, to the program. Consequently, the astute energy management coordinator will "stack the deck" in his or her first set of projects. These projects should have a rapid payback, a high probability of success, and few negative consequences.

These ideal projects are not as difficult to find as you might expect. Every plant has a few good opportunities, and the energy management coordinator should be looking for them.

One good example involved a rather dimly lit refrigerator warehouse area. Mercury vapor lamps were used in this area. The local energy management coordinator did a relamping project. He switched from mercury vapor lamps to high pressure sodium lamps (a significantly more efficient source) and carefully designed the system to improve the lighting levels. Savings were quite large; less energy was needed for lighting; less "heat of light" had to be refrigerated; and, most important, the employees liked it. Their environment was improved since light levels were higher than before.

Other examples you should consider include:

1. Repairing steam leaks. Even a small leak can be very expensive over a year and quite uncomfortable for employees working in the area.

2. Insulating steam, hot water, and other heated fluid lines and tanks. Heat loss through an uninsulated steam line can be quite large, and the surrounding air may be heated unnecessarily.

3. Install high efficiency motors. This saves dramatically on the electrical utility cost in many cases, and has no negative employee consequences. However, the employees should be told about the savings since motor efficiency improvement has no physically discernible effect, unlike the lighting example above.

This list only begins to touch on the possibilities, and what may be glamorous for one facility might not be for another. All facilities, however, do have such opportunities. Remember, highly successful projects should be accompanied by publicity at all stages of the program—especially at the beginning.

## 1.5 MANAGEMENT OF THE PROGRAM

### 1.5.1 Establishing objectives in an Energy Management Program

Creativity is a vital element in the successful execution of an energy management program, and management should do all it can to encourage creativity rather than stifle it. Normally, this implies a *laissez-faire* approach by management with adequate monitoring. Management by objectives (MBO) is often utilized. If TQM is being implemented in a facility, then employee teams should foster this interest and creativity.

Goals need to be set, and these goals should be tough but achievable, measurable, and specific. They must also include a deadline for accomplishment. Once management and the energy management coordinator have agreed on the goals and established a good monitoring or reporting system, the coordinator should be left alone to do his/her job.

The following list provides some examples of such goals:

- Total energy per unit of production will drop by 10 percent the first year and an additional 5 percent the second.
- Within 2 years all energy consumers of 5 million British thermal units per hour or larger will be separately metered for monitoring purposes.
- Each plant in the division will have an active energy management program by the end of the first year.
- All plants will have contingency plans for gas curtailments of varying duration by the end of the first year.
- All boilers of 50,000 lb/hour or larger will be examined for waste heat recovery potential the first year.

The energy management coordinator must quickly establish the reporting systems to measure progress toward the goals and must develop the strategy plans to ensure progress. Gantt or CPM charting is often used to aid in the planning and assignment of responsibilities.

Some concepts or principles that aid the EMC in this execution are the following:

- Energy costs, not just Btus, are to be controlled. This means that any action that reduces energy costs is fair game. Demand shedding or leveling is an example activity that saves dollars but does not directly save Btus.
- Energy needs should be recognized and billed as a direct cost, not as overhead. Until the energy flow can be measured and charged to operating cost centers, the program will not reach its ultimate potential.

- Only the main energy functions need to be metered and monitored. The Pareto or ABC principle states that the majority of the energy costs are incurred by only a few machines. These high-use machines should be watched carefully.

### 1.5.2 A Model Energy Management Program

Headquartered in St. Paul, MN [5], the 3M Company is an excellent example of a longtime successful energy management program in a large corporation. 3M is a diversified manufacturing company with more than 50 major product lines; it makes some 50,000 products at over 50 factory locations in the U.S. Their energy management objective is to use energy as efficiently as possible in all operations; management believes that all companies have an obligation to conserve energy and all natural resources.

Energy productivity at 3M's US operations improved over 80% from 1973-2010. Their energy management programs saved over $70 million in 1996, and more than $1.5 billion in energy expenses from 1973-2004. From 1998—2005, they reduced overall energy use by 29% in their worldwide operations. From 2006-2011, 3M increased their yearly energy use reduction goal to 5% per year. Also they reported a cumulative savings of $100 million from 2005-2011 [8]. Their program is staffed by six people who educate and motivate all levels of personnel on the benefits of energy management. The categories of programs implemented by 3M include: conservation, maintenance procedures, utility operation optimization, efficient new designs, retrofits through energy surveys, and process changes.

Energy efficiency goals at 3M are set and then the results are measured against a set standard in order to determine the success of the programs. The technologies that have resulted in the most dramatic improvement in energy efficiency include: heat recovery systems, high efficiency motors, variable speed drives, computerized facility management systems, steam trap maintenance, combustion improvements, variable air volume systems, thermal insulation, cogeneration, waste steam utilization, and process improvements. Integrated manufacturing techniques, better equipment utilization and shifting to non-hazardous solvents have also resulted in major process improvements.

The energy management program at 3M has worked well, but management is not yet satisfied. Their goal is to further improve energy efficiency at a rate of 3 percent per year for the next five years, 2006-2010. They expect to substantially reduce their emissions of waste gases and liquids, to increase the energy recovered from wastes, and to constantly increase the profitability of their operations. 3M continues to stress the importance that efficient use of energy can have on industrial productivity.

## 1.6 ENERGY ACCOUNTING

Energy accounting is a system used to keep track of energy consumption and costs. "Successful corporate-level energy managers usually rank energy accounting systems right behind commitment from top corporate officials when they list the fundamentals of an ongoing energy conservation program. If commitment from the top is motherhood, careful accounting is apple pie."*

A basic energy accounting system has three parts: energy use monitoring, an energy use record, and a performance measure. The performance measure may range from a simple index of Btu/ft$^2$ or Btu/unit of production to a complex standard cost system complete with variance reports. In all cases, energy accounting requires metering. Monitoring the energy flow through a cost center, no matter how large or small, requires the ability to measure incoming and outgoing energy. The lack of necessary meters is probably the largest single deterrent to the widespread utilization of energy accounting systems.

### 1.6.1 Levels of Energy Accounting

As in financial accounting, the level of sophistication or detail of energy accounting systems varies considerably from company to company. A very close correlation can be developed between the levels of sophistication of financial accounting systems and those of energy accounting systems. This is outlined in Figure 1-11.

Most companies with successful energy management programs have passed level 1 and are working toward the necessary submetering and reporting systems for level 2. In most cases, the subsequent data are compared to previous years or to a particular base year. However, few companies have developed systems that will calculate variations and find causes for those variations (level 3). Two notable exceptions are General Motors and Carborundum. To our knowledge, few companies have yet completely developed the data and procedures necessary for level 4, a standard Btu accounting system. Some examples of detailed energy accounting can be found in [6].

### 1.6.2 Performance Measures

#### 1.6.2.1 Energy Utilization Index

A very basic measure of a facility's energy performance is called the Energy Utilization Index (EUI). This is a statement of the number of Btus of energy used annually per square foot of conditioned space. To compute

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*"Accounting of Energy Seen Corporate Must," *Energy User News,* Aug. 27, 1979, p. 1.

| *Financial* | *Energy* |
|---|---|
| 1. General accounting | 1. Effective metering, development of reports, calculation of energy efficiency indices |
| 2. Cost accounting | 2. Calculation of energy flows and efficiency of utilization for various cost centers; requires substantial metering |
| 3. Standard cost accounting historical standards | 3. Effective cost center metering of energy and comparison to historical data; complete with variance reports and calculation of reasons for variation |
| 4. Standard cost accounting engineered standards | 4. Same as 3 except that standards for energy consumption are determined through accurate engineering models |

**Figure 1-11. Comparison between Financial and Energy Accounting**

the EUI, all of the energy used in the facility must be identified, the total Btu content tabulated, and the total number of square feet of conditioned space determined. The EUI is then found as the ratio of the total Btu consumed to the total number of square feet of conditioned space.

**Example 1.1**—Consider a building with 100,000 square feet of floor space. It uses 1. 76 million kWh and 6.5 million cubic feet of natural gas in one year. Find the Energy Utilization Index (EUI) for this facility.

**Solution:** Each kWh contains 3412 Btu and each cubic foot of gas contains about 1000 Btu. Therefore the total annual energy use is:

$$\begin{aligned}\text{Total energy use} &= (1.76 \times 10^6 \text{ kWh}) \times (3412 \text{ Btu/kWh}) \\ &\quad + (6.5 \times 10^6 \text{ ft}^3) \times (1000 \text{ Btu/ft}^3) \\ &= 6.0 \times 10^9 + 6.5 \times 10^9 \\ &= 1.\ 25 \times 10^{10} \text{ Btu/yr}\end{aligned}$$

Dividing the total energy use by $10^5$ ft$^2$ gives the EUI:

$$\begin{aligned} \text{EUI} &= (1.25 \times 10^{10} \text{ Btu/yr})/(10^5 \text{ ft}^2) \\ &= 125{,}000 \text{ Btu/ft}^2\text{/yr} \end{aligned}$$

---

The average building EUI is 89,800 Btu/ft$^2$/yr; the average office building EUI is 92,900 Btu/ft$^2$/yr. Figure 1-12 shows the range of energy intensiveness in 1000 Btu/ft$^2$/yr for the twelve different types of commercial facilities listed [7].

### 1.6.2.2 Energy Cost Index

Another useful performance index is the Energy Cost Index or ECI. This is a statement of the dollar cost of energy used annually per square foot of conditioned space. To compute the ECI, all of the energy used in the facility must be identified, the total cost of that energy tabulated, and the total number of square feet of conditioned space determined. The ECI is then found as the ratio of the total annual energy cost for a facility to the total number of square feet of conditioned floor space of the facility.

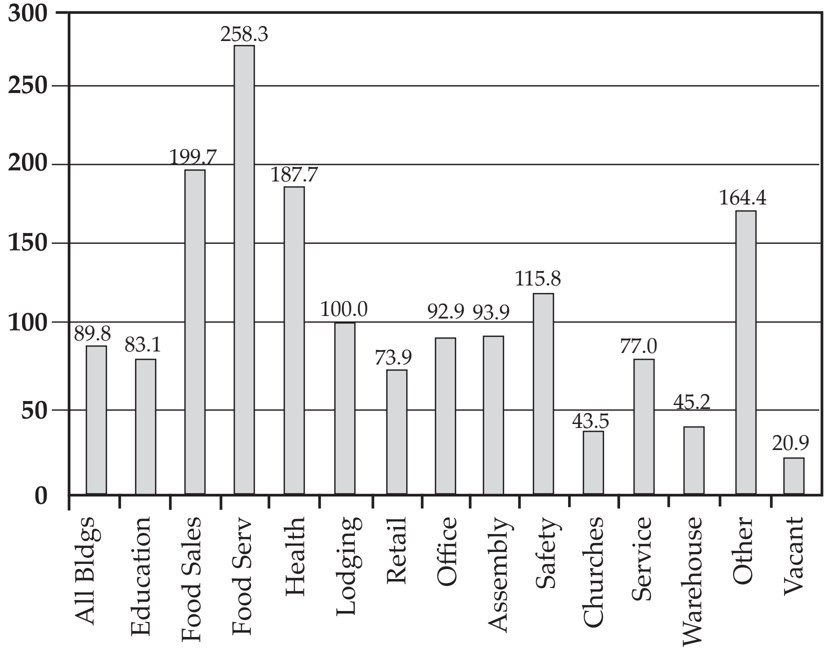

**Figure 1-12. Building Energy Utilization Index, 2003 Data. (In Thousand Btu per Sq Ft per Year).** Source—U.S. Department of Energy EIA 4/2011)

**Example 1.2** Consider the building in Example 1.1. The annual cost for electric energy is \$115,000 and the annual cost for natural gas is \$32,500. Find the Energy Cost Index (ECI) for this facility.

**Solution:** The ECI is the total annual energy cost divided by the total number of conditioned square feet of floor space.

$$\text{Total energy cost} = \$115{,}000 + \$32{,}500 = \$147{,}500/\text{yr}$$

Dividing this total energy cost by 100,000 square feet of space gives:

$$\text{ECI} = (\$147{,}500/\text{yr})/(100{,}000\ \text{ft}^2) = \$1.48/\text{ft}^2/\text{yr}$$

The Energy Information Administration data for 2003 showed a value of the ECI for the average building as \$1.51/ft$^2$/yr. The ECI for an average office building was \$1.71/ft$^2$/yr.

#### 1.6.2.2 One-Shot Productivity Measures

The purpose of a one-shot productivity measure is illustrated in Figure 1-13. Here the energy utilization index is plotted over time, and trends can be noted.

Significant deviations from the same period during the previous year should be noted and explanations sought. This measure is often used to justify energy management activities or at least to show their effect. For example, in Figure 1-13 an energy management (EM) program was started at the beginning of year 2. Its effect can be noted by comparing peak summer consumption in year 2 to that of year 1. The decrease in peaks indicates that this has been a good program (or a mild summer, or both).

Table 1-3 shows some often-used indices. Some advantages and disadvantages of each index are listed, but specific applications will require careful study to determine the best index.

Table 1-4 proposes some newer concepts. Advantages and disadvantages are shown, but since most of these concepts have not been utilized in a large number of companies, there are probably other advantages and disadvantages not yet identified. Also, there are an infinite number of possible indices, and only three are shown here.

### 1.6.3 An Example Energy Accounting System

General Motors Corporation has a strong energy accounting sys-

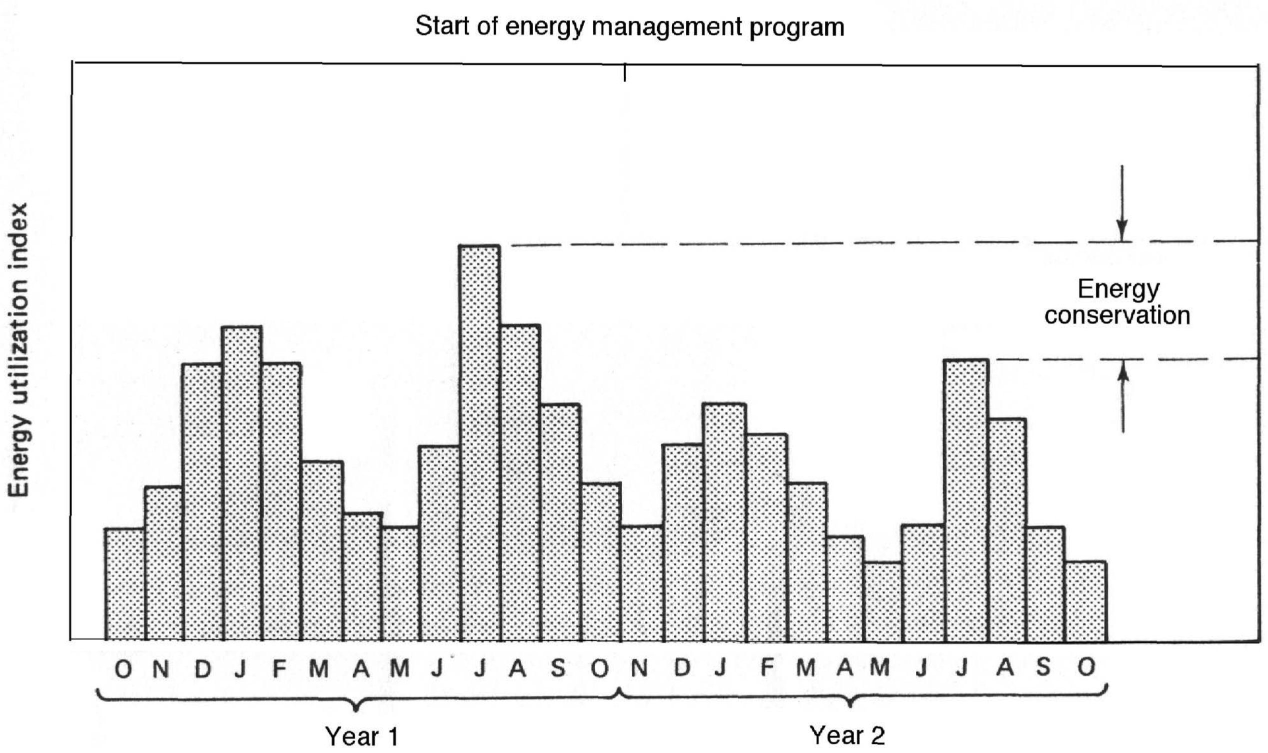

Figure 1-13
One-shot Energy Productivity Measurement.

### Table 1-3. Commonly Used Indices

| | *Productivity indicator* | *Advantages* | *Disadvantages* |
|---|---|---|---|
| 1. | Btu/unit of production | 1. Concise, neat<br>2. Often accurate when process energy needs are high<br>3. Good for interplant and company comparison when appropriate | 1. Difficult to define and measure "units"<br>2. Often not accurate (high HVAC* and lighting makes energy nonlinear to production) |
| 2. | Btu/degree day | 1. Concise, neat, best used when HVAC* is a majority of energy bill<br>2. Often accurate when process needs are low or constant<br>3. Very consistent between plants, companies, etc. (all mfg can measure degree days) | 1. Often not accurate (disregards process needs)<br>2. Thermally heavy buildings such as mfg plants usually do not respond to degree days |
| 3. | Btu/$\text{ft}^2$ | 1. Concise, neat<br>2. Accurate when process needs are low or constant and weather is consistent<br>3. Very consistent (all mfg can measure square feet)<br>4. Expansions can be incorporated directly | 1. No measure of production or weather<br>2. Energy not usually linearly proportional to floor space (piecewise linear?) |
| 4. | Combination, e.g., Btu/unit-degree day-$\text{ft}^2$ or Btu/unit-degree day | 1. Measures several variables<br>2. Somewhat consistent, more accurate than above measures<br>3. More tailor-made for specific needs | 1. Harder to comprehend |

*Heating, ventilating, and air conditioning.

**Table 1-4.**
**Proposed Indices**

| | *Productivity indicator* | *Advantages* | *Disadvantages* |
|---|---|---|---|
| 1. | Btu/sales dollar | 1. Easy to compute | 1. Impact of inflation |
| 2. | $\dfrac{\$\text{ energy}}{(\$\text{ sales}) \text{ or } (\$\text{ profit}) \text{ or } (\$\text{ value added})}$ | 1. Really what's desired<br>2. Inflation cancels or shows changing relative energy costs<br>3. Shows energy management results, not just conservation (e.g., fuel switching, demand leveling, contingency planning) | 1. Very complex, e.g., lots of variables affect profit including accounting procedures<br>2. Not good for general employee distribution |
| 3. | Btu/DL hour (or machine hour or shift) where DL = direct labor | 1. Almost a measure of production (same advantage as in Table 1-3)<br>2. Data easily obtained when already available<br>3. Comparable between plants or industries<br>4. Good for high process energy needs | 1. More complex, e.g., can't treat a DL hour like a unit of production<br>2. Energy often not proportional to labor or machine input, e.g., high HVAC and lighting |

tem which uses an energy responsibility method. According to General Motors, a good energy accounting system is implemented in three phases: (1) design and installation of accurate metering, (2) development of an energy budget, and (3) publication of regular performance reports including variances. Each phase is an important element of the complete system.

### 1.6.3.1 The GM system

*Phase 1—Metering*. For execution of a successful energy accounting program, energy flow must be measured by cost center. The designing of cost center boundaries requires care; the cost centers must not be too large or too small. However, the primary design criterion is how much energy is involved. For example, a bank of large electric induction heat-treating furnaces might need separate metering even if the area involved is relatively small, but a large assembly area with only a few energy-consuming devices may require only one meter. Flexibility is important since a cost center that is too small today may not be too small tomorrow as energy costs change.

The choice of meters is also important. Meters should be accurate, rugged, and cost effective. They should have a good turndown ratio; a turndown ratio is defined as the ability to measure accurately over the entire range of energy flow involved.

Having the meters is not enough. A system must be designed to gather and record the data in a useful form. Meters can be read manually, they can record information on charts for permanent records, and/or they can be interfaced with microcomputers for real-time reporting and control. Many energy accounting systems fail because the data collection system is not adequately designed or utilized.

*Phase 2—Energy Budget*. The unique and perhaps vital aspect of General Motors' approach is the development of an energy budget. The GM energy responsibility accounting system is somewhere between levels 3 and 4 of Figure 1-11. If a budget is determined through engineering models, then it is a standard cost system and it is at level 4. There are two ways to develop the energy budget: statistical manipulation of historical data or utilization of engineering models.

**The Statistical Model.** Using historical data, the statistical model shows how much energy was utilized and how it compared to the standard year(s), but it does not show how efficiently the energy was used. For example, consider the data shown in Table 1-5.

**Table 1-5. Energy Data for Statistical Model[a]**

| | *1995* | *1996* | *1997* |
|---|---|---|---|
| Total energy (units) | 1,000 | 1,100 | 1,050 |
| Production (units) | 600 | 650 | 650 |
| Square feet | 150,000 | 150,000 | 170,000 |
| Degree days (heating) | 6,750 | 6,800 | 6,800 |

[a]Taken, in part, from R.P. Greene, (see the Bibliography).

The statistical model assumes that the base years are characteristic of all future years. Consequently, if 1996 produced 600 units with the same square footage and degree days as 1995, 1000 units of energy would be required. If 970 units of energy were used, the difference (30 units) would be due to conservation.

We could use multiple linear regression to develop the parameters for our model, given as follows:

$$\text{energy forecast} = a(\text{production level}) + b(\text{ft}^2) + c(\text{degree days}) \qquad (1\text{-}1)$$

We can rewrite this in the following form:

$$X_4 = aX_1 + bX_2 + cX_3$$

where $X_1$= production (units)

$X_2$ = floor space (ft$^2$)

$X_3$ = weather data (degree days)

$X_4$ = energy forecast (Btu)

Degree days are explained in detail in Chapter Two, section 2.1.1.2. Their use provides a simple way to account for the severity of the weather, and thus the amount of energy needed for heating and cooling a facility. Of course, the actual factors included in the model will vary between companies and need to be examined carefully.

Multiple linear regression estimates the parameters in the universal regression model in Equation 1-1 from a set of sample data. Using the base years, the procedure estimates values for parameters a, b, and c in Equation 1-1 in order to minimize the squared error where

$$\text{squared error} = \sum_{\substack{\text{base}\\\text{years}}} \left(X_4^i - X_4\right)^2 \qquad (1\text{-}2)$$

with $X_4$ = energy forecast by model

$X_4^i$ = actual energy usage

The development and execution of this statistical model is beyond the scope of this book. However, regardless of the analytical method used, a statistical model does not determine the amount of energy that ought to be used. It only forecasts consumption based on previous years' data.

**The engineering model.** The engineering model attempts to remedy the deficiency in the statistical model by developing complete energy balance calculations to determine the amount of energy theoretically required. By using the first law of thermodynamics, energy and mass balances can be completed for any process. The result is the energy required for production. Similarly, HVAC and lighting energy needs could be developed using heat loss equations and other simple calculations. Advantages of the engineering model include improved accuracy and flexibility in reacting to changes in building structures, production schedules, etc. Also, computer programs exist that will calculate the needs for HVAC and lighting.

*Phase 3—Performance Reports*. The next step is the publication of energy performance reports that compare actual energy consumption with that predicted by the models. The manager of each cost center should be evaluated on his or her performance as shown in these reports. The publication of these reports is the final step in the effort to transfer energy costs from an overhead category to a direct cost or at least to a direct overhead item. One example report is shown in Figure 1-14.

Sometimes more detail on variance is needed. For example, if consumption were shown in dollars, the variation could be shown in dollars and broken into price and consumption variation. Price variation is calculated as the difference between the budget and the actual unit price times the present actual consumption. The remaining variation would be due to a change in consumption and would be equal to the change in consumption times the budget price. This is illustrated in Example 1.3. Other categories of variation could include fuel switching, pollution control, and new equipment.

However, had energy consumption not been reduced, the total energy cost would have been:

$$2125(4.50) + 6400(3.12) + 2571(4.46) = \$40{,}997.$$

The total cost avoidance therefore was:

$$\$40{,}997 - \$34{,}000 = \$6997$$

| | Actual | Budget | Variance | % variance |
|---|---|---|---|---|
| Department A | | | | |
| Electricity | 2000 | 1500 | +500 | +33.3% |
| Natural gas | 3000 | 3300 | –300 | –9.1% |
| Steam | 3500 | 3750 | –250 | –6.7% |
| Total | 8500 | 8550 | –50 | –0.6% |
| | | | | |
| Department B | | | | |
| Electricity | 1500 | 1600 | –100 | –6.2% |
| Natural gas | 2000 | 2400 | –400 | –16.7% |
| Fuel oil | 1100 | 1300 | – 200 | –15.4% |
| Coal | 3500 | 3900 | – 400 | –10.2% |
| Total | 8100 | 9200 | – 1100 | – 11.9% |
| | | | | |
| Department C | | | | |
| • | | | | |
| • | | | | |
| • | | | | |

**Figure 1-14. Energy Performance Report ($10^6$Btu)**

which is the drop in consumption times the actual price or

$$(2125 - 2000)\ 4.5 + (6400 - 4808)\ 3.12 + (2571 - 2242)\ 4.46 = \$6997$$

This problem of increased energy costs despite energy management savings can arise in a number of ways. Increased production, plant expansion, or increased energy costs can all cause this result.

## 1.7 ENERGY MONITORING, TARGETING AND REPORTING*

### 1.7.1 Introduction

**Energy Monitoring, Targeting and Reporting (MT&R)** is a powerful management technique for

- analyzing the historical energy performance of industrial, commercial, and institutional facilities
- setting energy reduction targets

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*This section was written by Mr. Doug Tripp, P. Eng., Executive Director, Canadian Institute for Energy Training,; and Mr. Stephen Dixon, President, TdS Dixon Inc.

**Example 1.3**

The table shown in Figure 1-15 portrays a common problem in energy management reporting. The energy management program in this heat treating department was quite successful. When you examine the totals, you see that the total consumption (at old prices) was reduced by $5631. The total energy cost, however, went up by $500, which was due to a substantial price variation of $6131. Consequently, total energy costs increased to $34,000.

| Heat Treating Department | [A] Actual $ | [B] Budget $ | [C] Unit price (budget) | [D] Unit price (actual) | [E] A - B[a] variance | [F] (D - C)A[b] price variance | [G] E – F or (B[b] – A[b])C consumption variance |
|---|---|---|---|---|---|---|---|
| | $10^6$ Btu | $10^6$ Btu | $/$10^6$ Btu | $/$10^6$ Btu | | | |
| **Electricity** | | | | | | | |
| Cost | $9,000 | $8,500 | $4.00 | $4.50 | +$500 | +$1000 | –$500 |
| Use | 2,000 | 2,125 | — | — | — | — | — |
| **Natural gas** | | | | | | | |
| Cost | 15,000 | 16,000 | 2.50 | 3.12 | –1000 | +2980 | –3980 |
| Use | 4,808 | 6,400 | — | — | — | — | — |
| **Steam** | | | | | | | |
| Cost | 10,000 | 9,000 | 3.50 | 4.46 | +1000 | +2151 | –1151 |
| Use | 2,242 | 2,571 | — | — | — | — | — |
| Total cost | $34,000 | $33,500 | — | — | +$500 | +$6131 | –$5631 |

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[a] Measured in $

[b] Measured in $10^6$ Btu

**Figure 1-15. Energy Cost in Dollars by Department with Variance Analysis**

- controlling current energy performance
- and, projecting future energy budgets.

It is a technique that has proven its effectiveness in achieving energy cost savings in the range five to fifteen percent as a direct consequence of effective performance monitoring, and in creating the management information needed to identify and implement energy efficiency measures. Further, it provides a framework for savings verification when measures are implemented.

The working definitions that commonly apply are the following:

- **Energy Monitoring** is the regular collection and analysis of information on energy use. Its purpose is to establish a basis of management control, to determine when and why energy consumption is deviating from an established pattern, and to provide a basis for taking management action where necessary.

- **Targeting** is the identification of levels of energy consumption towards which it is desirable, as a management objective, to work.

- **Reporting** closes the loop, by putting the management information generated in a form that enables ongoing control of energy use, the achievement of reduction targets, and the verification of savings.

MT&R is built around one key statistical technique: CUSUM (Cumulative Sum of Differences) analysis of the variance between energy consumption predicted by an energy performance model (EPM), and the actual measured consumption. Ancillary functions that are derived from the CUSUM analysis are a target-setting methodology, and the application of energy control charts for real-time management of performance.

The key steps in an effective MT&R process are:

- measurement of energy consumption over time
- measurement of the independent variables that influence energy consumption (weather, production, occupancy) over corresponding time intervals
- development of a relationship (the energy performance model) between energy and the independent variables
- historical analysis of energy performance using CUSUM, and application of the CUSUM trend into the future

- definition of reduction targets
- frequent comparison of actual consumption to targets
- reporting of consumption and target variances
- taking action to address variances and ensure targets are met.

The achievement of energy cost savings is the primary objective of MT&R, but there are other benefits as well, including:

- improved budgeting and forecasting
- improved product/service costing
- tracking and verification of energy efficiency retrofits
- opportunities for improved operation and maintenance practices.

### 1.7.1.1 MT&R and Continuous Improvement

Monitoring and target setting have elements in common and they share much of the same information. As a general rule, however, monitoring comes before target setting because without monitoring you cannot know precisely where you are starting from or decide if a target has been achieved. The reporting phase not only supports management control, but also provides for accountability in the relationship between performance and targets.

MT&R is consistent with other continuous improvement techniques applied in organizations, and should be viewed as an ongoing, cyclical process, as Figure 1-16 suggests.

The cycle begins with any measured energy data presently available, typically energy bills or invoices. Once assembled the data can be analyzed to reveal patterns, trends and consumption statistics. The reporting of the information resulting from this analysis can be used to prompt actions that produce results, typically the reduction of consumption and costs. Subsequent measurements and analysis reveal the actual result of the actions. The process then enters another cycle of measurement, analysis and action.

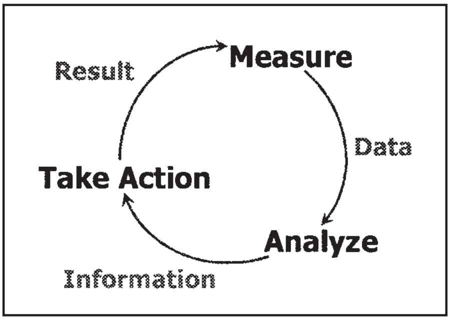

**Figure 1-16. The Measure-analyze-action Cycle**

### 1.7.1.2 Energy Cost Center

The organizational basis for MT&R is the energy cost center (ECC). An ECC is a unit for which energy use may be measured along with other factors that influence the energy consumption. For example, the ECC might be a single building in a portfolio of properties, a production unit or department in a plant, or a major energy consuming system such as the heating plant.

Basic criteria for the designation of an ECC are:

- energy consumption can be measured in isolation
- the cost of measurement can be justified by potential savings
- the ECC must correspond to existing business structures
- someone must be accountable for the ECC
- a factor of influence must be measurable.

### 1.7.1.3 Units of Measure

An energy monitoring and targeting system must measure data for all energy forms utilized in the ECC. While the goal of the system is to reduce costs, dollars are not good universal measurement units for basic data. Unit prices tend to fluctuate over time making comparison of present to previous energy usage difficult if not impossible. Current unit prices can be applied to calculated energy savings to determine total cost avoidance.

Wherever possible, data should be recorded in physically measurable units (typically the units of purchase such as gallons, litres, therms, kWh, $ft^3$, $M^3$ and so on). If more than one energy source is being used by the ECC, it is necessary to convert the units of purchase to a common unit using the appropriate energy equivalence factors for each form.

## 1.7.2 Principles of Energy Monitoring

Energy monitoring involves the development of an energy performance model (EPM) that quantifies a relationship between consumption and the applicable independent variables, and the comparison of performance predicted by the model to actual performance by means of CUSUM analysis. Although the EPM can be developed in a number of ways, it most commonly involves the use of regression analysis.

### 1.7.2.1 Independent Variables

In addition to energy data for each ECC, the applicable factors of influence, or independent variables, must be measured. Some examples include:

- **Operating Hours/Occupancy—**In office buildings, schools, hospitals, retail stores, warehouses, accommodation facilities, energy consumption depends primarily on the weather through the heating and cooling systems, and secondarily on patterns of use such as operating hours and occupancy. Electricity and fuel each have their own dependencies or combination of dependencies specific to each facility's systems.
- **Production Level—**Energy use in manufacturing and industrial facilities depends strongly on production level or a measure of the facility's output, in units, tons, or some other appropriate unit. Also, energy use in these operations often exhibits a strong dependence upon weather.
- **Degree Days—**Degree days are a measure of the outside temperature for a given period and can often be used to predict the amount of heating and cooling energy a building requires.

Heating degree days (HDD), for the winter season indicate the difference between the outside temperature and a baseline (typically 65°F or 18°C) and how long that difference exists for. Likewise cooling degree days (CDD) indicate the difference above a base temperature (typically 72°C or 22°C) for the cooling season.

Degree days can be derived from temperature measurements at the facility, or can be obtained from weather services and some utilities. For a basic MT&R system, degree days from a nearby site are often adequate although they may only be available on a monthly basis. See Section 2.1.1.2.

### 1.7.2.2 Functional Relationship between Energy and the Independent Variables

Energy used in production processes typically heats, cools, changes the state of, or moves material. Obviously it is impossible to generalize as industrial processes are both complex and widely varied. However, a similar theoretical assessment of specific processes as that done for degree-days will yield a similar conclusion: that is, there is reason to expect that energy plotted against production will also produce a straight line of the general form:

$$y = mx + c \tag{1-5}$$

where c, the intercept (and, no load or zero production energy consumption), and m, the slope are empirical coefficients, characteristic of the system being analyzed. See Figure 1-17.

1.7.2.3 Establishing the Energy Performance Model

Energy use data alone are of very limited usefulness in understanding the nature of the energy system, identifying opportunities for efficiency improvement, and controlling energy use in the future. Refining data to information that facilitates these functions involves analysis, following steps illustrated here.

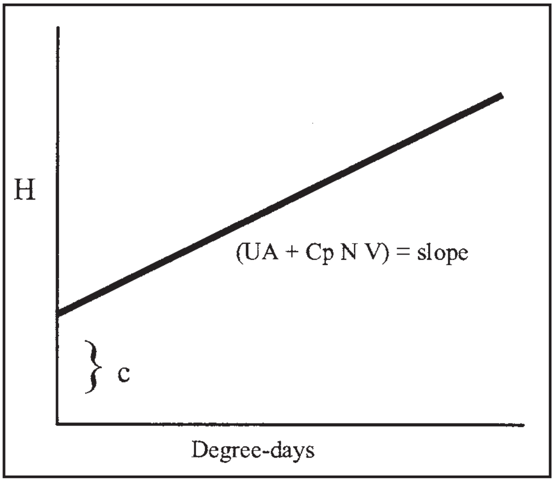

**Figure 1-17. Relationship between Degree-days and Heat Load**

Three basic methods exist for establishing a model:

- **previous year's data—**simply using last year as a predictor of this year's consumption. Typically only useful when there are no significant factors of influence.
- **regression analysis—**a statistical approach based upon historical consumption and the factors of influence.
- **simulation model—**using complex numerical computer models to simulate the energy consumption.

The most common method for a basic system is regression analysis.

In many instances linear regression of energy consumption against a single independent variable (degree-days or production) generates a valid energy performance model. In some cases, multivariant linear regression, for example against degree-days and production in a plant for which there is significant dependence on weather, is a better representation of the energy relationship.

To illustrate, two data sets are shown below, one for a building with energy consumption driven by degree days, and one for a plant in which the driver is production. In each case, the scatter plot produced when consumption is plotted against the independent variable is subjected to linear regression, with the results shown in Figure 1-18.

The graph produces an energy performance model equation as shown. That is,

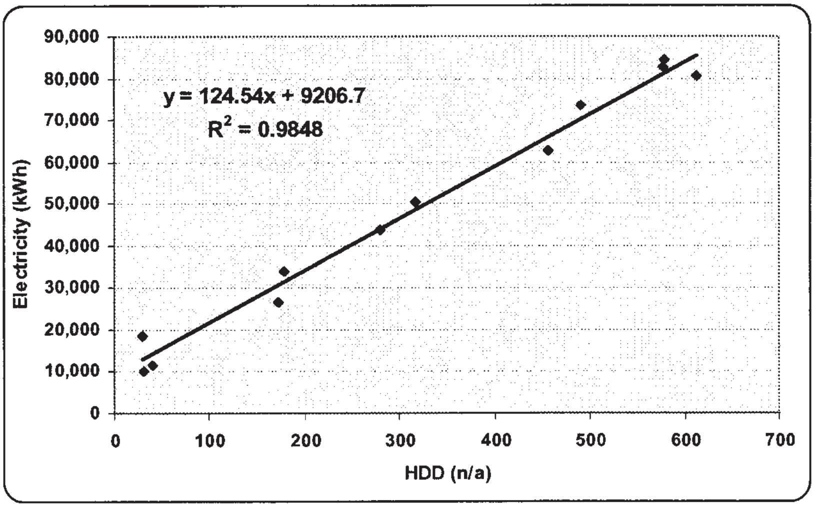

**Figure 1-18. Regression Analysis of School Energy Data**

Electricity (kWh) = 124.54 × HDD + 9206.7 (1-6)

The two parameters in the equation have a physical meaning:

- the slope of the line, 124.54 represents the incremental energy consumption per heating degree day
- the intercept, 9206.7, represents the non-heating or weather-independent load.

**Table 1-6. Sample Energy Data for a School**

| *Month* | *Heating Degree Days* | *Total Electricity kWh* |
|---|---|---|
| Feb 01 | 577 | 82,800 |
| Mar 01 | 613 | 80,640 |
| Apr 01 | 490 | 73,440 |
| May 01 | 279 | 43,920 |
| Jun 01 | 179 | 33,840 |
| Jul 01 | 29 | 18,720 |
| Aug 01 | 31 | 10,080 |
| Sep 01 | 40 | 11,520 |
| Oct 01 | 172 | 26,640 |
| Nov 01 | 316 | 50,400 |
| Dec 01 | 456 | 62,640 |
| Jan 02 | 579 | 84,240 |

Assessment of building performance may involve an examination of each of these components of load separately.

Similarly, a plant production data-set in Table 1-7 generates a regression model as in Figure 1-19.

**Table 1-7. Sample Energy Data for a Food Processing Plant**

| *Month* | *Production lb.* | *Total Process Energy, MMBtu* |
|---|---|---|
| Jan 02 | 39,600 | 137,243 |
| Feb 02 | 21,120 | 107,620 |
| Mar 02 | 15,840 | 94,630 |
| Apr 02 | 13,200 | 102,649 |
| May 02 | 44,880 | 152,845 |
| Jun 02 | 47,520 | 171,792 |
| Jul 02 | 31,680 | 126,754 |
| Aug 02 | 10,560 | 84,905 |
| Sep 02 | 29,040 | 120,510 |
| Oct 02 | 23,760 | 108,051 |
| Nov 02 | 10,560 | 87,491 |
| Dec 02 | 13,200 | 89,379 |
| Jan 03 | 36,960 | 131,255 |
| Feb 03 | 40,920 | 144,886 |
| Mar 03 | 43,560 | 145,882 |
| Apr 03 | 50,160 | 158,760 |
| May 03 | 10,560 | 81,102 |
| Jun 03 | 14,520 | 86,234 |
| Jul 03 | 39,600 | 129,613 |
| Aug 03 | 21,120 | 98,710 |
| Sep 03 | 16,632 | 88,233 |
| Oct 03 | 29,040 | 112,643 |
| Nov 03 | 18,480 | 92,912 |
| Dec 03 | 44,880 | 142,198 |
| Jan | 50,160 | 147,453 |
| Feb 04 | 42,240 | 147,231 |
| Mar 04 | 31,680 | 123,359 |

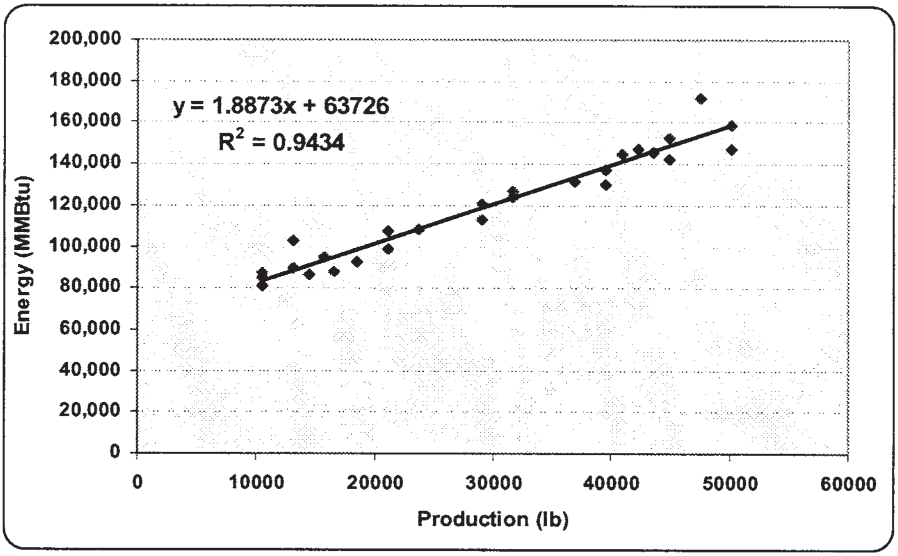

**Figure 1-19. Regression Analysis of Food Processing Plant Energy Consumption**

Here the energy performance model is

$$\text{Process Energy (MMBtu)} = 1.8873 \times \text{Production (lb.)} + 63{,}726 \qquad (1\text{-}7)$$

in which, once again, we see the two components of energy consumption, the production-related component (1.9929 MMBtu/lb.) and the production-unrelated base load (65,546 MMBtu).

In each of these examples, the $R^2$ value indicates the level of confidence we have in the fit of the regression line to the scatter of points.

In the industrial example, it is important to note that many points lie above and below the regression line. This may indicate that energy performance has changed at some point within the 27 months considered. If the points were plotted chronologically, it might become evident that the early points fall above the line (i.e. at relatively higher energy consumption for given production levels) while later points fall below the line (i.e. at relatively lower energy consumption), or vice versa.

If there has been a change in performance, either due to a deliberate action or for an as yet unknown reason, the regression model for the entire data set is not a useful basis for comparison; that is, we need a "baseline" period that is characterized by consistent performance or efficiency.

### *1.7.2.2.1 Defining the Baseline*

Finding a baseline period may involve trial and error analysis of the data, or it may be defined as a result of knowledge about plant operations. For the purposes of this illustration, let us suppose that it is known that the plant performed consistently for the first 12 months, at which point an improvement was implemented. The regression of the first 12 points in the data set yields Figure 1-20 and a new energy performance model for the baseline period.

The baseline relationship is

$$\text{Process Energy (MMBtu)} = 2.0078 \times \text{Production (lb.)} + 64{,}966 \qquad (1\text{-}8)$$

Comparison of Equations 1-7 and 1-8 immediately indicates two important findings:

- the production-related energy is lower for the entire data set than it was in the first 12 months (1.8873 vs. 2.0078 MMBtu/lb.)
- the production-unrelated energy is lower for the entire data set than it was in the first 12 months (63,726 vs. 64,966 MMBtu)

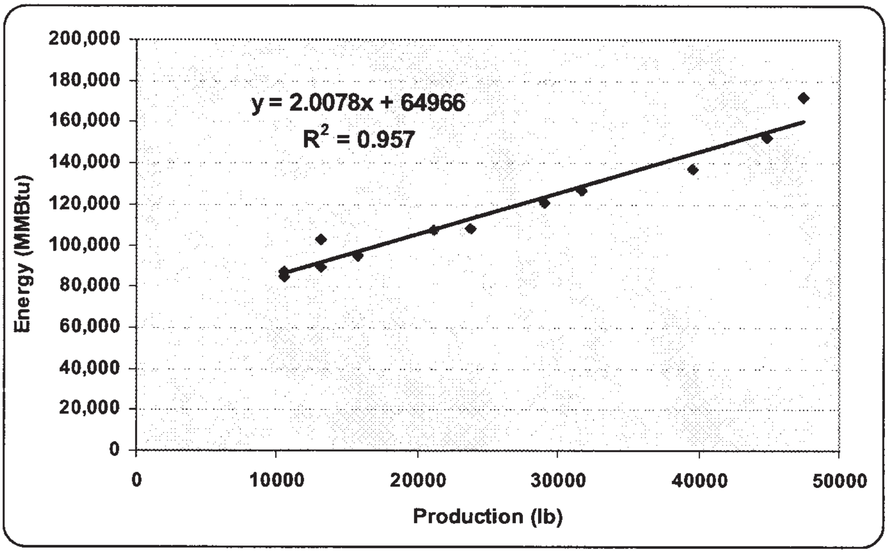

**Figure 1-20. Baseline Model for Food Processing Plant**

Both of these findings suggest that performance improvements have taken place to lower the overall energy consumption rates from what they were in the first year.

### 1.7.2.3 CUSUM Analysis

The baseline EPM, for the shaded months in Table 1-8, is used in CUSUM analysis.

- Predicted values of energy consumption are calculated from Equation 1-8 the actual production values.
- Variance is simply actual consumption-predicted consumption.
- CUSUM values are, as the name indicates, the cumulative algebraic sum of the variances.

So, for example:

the CUSUM value for Oct '02
= 5,389 (the cumulative sum for the previous month) +
(–4,621) (the variance for Oct '02).

The CUSUM values are plotted in a time series shown in Figure 1-22.

#### *1.7.2.3.1 Interpreting the CUSUM Graph*

The CUSUM graph reveals changes in energy performance at any point where there is a significant change in the slope of the line. A downward trending line indicates energy saved in comparison to the baseline performance, while an upward trending line indicates a higher rate of consumption.

After the first 12 months of the data set, a downward trend that continues until approximately month 18 is noted. At that point, the downward trend increases in rate, indicating that energy is being saved at a higher rate than in the previous 6 months; this trend continues until month 25. At month 25, another change in slope is observed, but this time to a lower rate of saving; this change indicates that one of the improvements, probably the second one, has stopped functioning, and that action is required to correct the malfunction. Comparison of the slopes for line segments 12-18 and 25-27 indicates that they appear to be approximately the same; that is, the rate of savings is the same in these two periods.

Overall, the graph indicates that a total of approximately 130,000

### Table 1-8. CUSUM Calculations for Food Processing Plant

| *Month* | *Production lb.* | *Total Process Energy, MMBtu* | *Predicted Process Energy MMBtu* | *Variance Actual— Predicted MMBtu* | *CUSUM MMBtu* |
|---|---|---|---|---|---|
| Jan 02 | 39,600 | 137,243 | 144,476 | –7,233 | –7,233 |
| Feb 02 | 21,120 | 107,620 | 107,371 | 248 | –6,985 |
| Mar 02 | 15,840 | 94,630 | 96,770 | –2,140 | –9,125 |
| Apr 02 | 13,200 | 102,649 | 91,469 | 11,179 | 2,054 |
| May 02 | 44,880 | 152,845 | 155,077 | –2,233 | –178 |
| Jun 02 | 47,520 | 171,792 | 160,378 | 11,414 | 11,235 |
| Jul 02 | 31,680 | 126,754 | 128,574 | –1,820 | 9,416 |
| Aug 02 | 10,560 | 84,905 | 86,169 | –1,263 | 8,152 |
| Sep 02 | 29,040 | 120,510 | 123,273 | –2,763 | 5,389 |
| Oct 02 | 23,760 | 108,051 | 112,672 | –4,621 | 768 |
| Nov 02 | 10,560 | 87,491 | 86,169 | 1,322 | 2,090 |
| Dec 02 | 13,200 | 89,379 | 91,469 | –2,090 | –0 |
| Jan 03 | 36,960 | 131,255 | 139,175 | –7,921 | –7,921 |
| Feb 03 | 40,920 | 144,886 | 147,126 | –2,240 | –10,161 |
| Mar 03 | 43,560 | 145,882 | 152,427 | –6,545 | –16,706 |
| Apr 03 | 50,160 | 158,760 | 165,679 | –6,919 | –23,625 |
| May 03 | 10,560 | 81,102 | 86,169 | –5,067 | –28,691 |
| Jun 03 | 14,520 | 86,234 | 94,120 | –7,886 | –36,577 |
| Jul 03 | 39,600 | 129,613 | 144,476 | –14,863 | –51,440 |
| Aug 03 | 21,120 | 98,710 | 107,371 | –8,661 | –60,101 |
| Sep 03 | 16,632 | 88,233 | 98,360 | –10,127 | –70,228 |
| Oct 03 | 29,040 | 112,643 | 123,273 | –10,630 | –80,858 |
| Nov 03 | 18,480 | 92,912 | 102,071 | –9,159 | –90,018 |
| Dec 03 | 44,880 | 142,198 | 155,077 | –12,879 | –102,897 |
| Jan 04 | 50,160 | 147,453 | 165,679 | –18,226 | –121,123 |
| Feb 04 | 42,240 | 147,231 | 149,777 | –2,546 | –123,669 |
| Mar 04 | 31,680 | 123,359 | 128,574 | –5,215 | –128,884 |

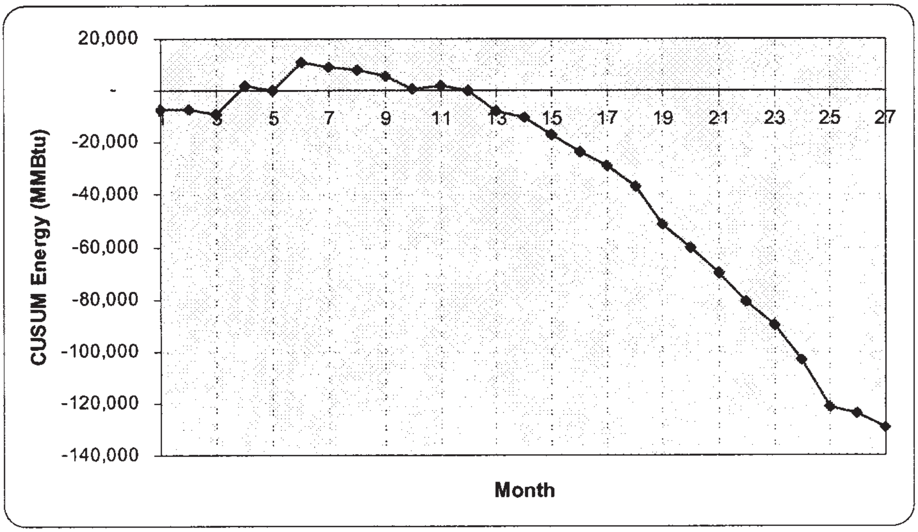

Figure 1-21. CUSUM Graph for Food Processing Plant

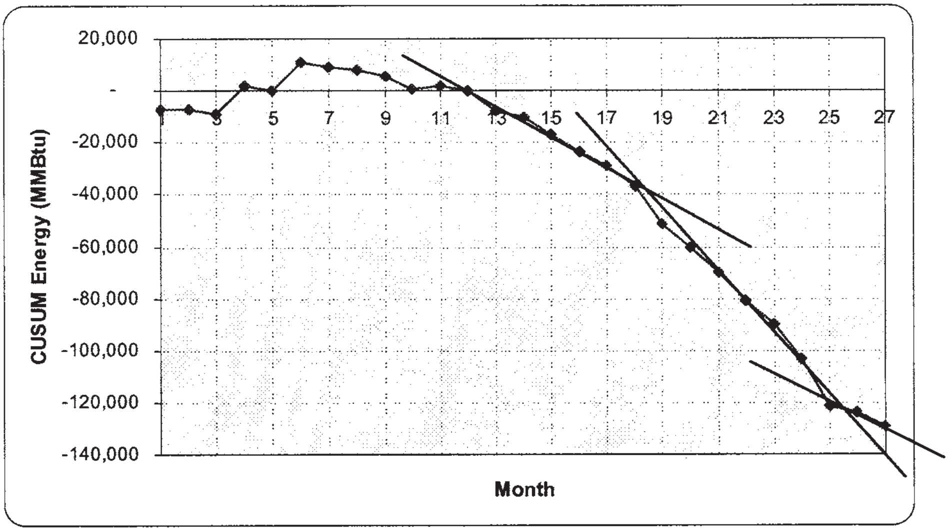

Figure 1-22. CUSUM Trends

MMBtu (actually 128,884 MMBtu from Table 1-8) has been saved in comparison to what would have been consumed had the baseline performance continued for the entire period.

### *1.7.2.3.2 Source of the Savings*

The CUSUM graph indicates when performance changes occurred, and what they achieved in terms of energy saved or wasted. It does not directly indicate how or why those changes occurred. However, further examination of the period of best performance, months 18 through 24 in the example, does give some further information. Figure 1-23 is the regression line for those months.

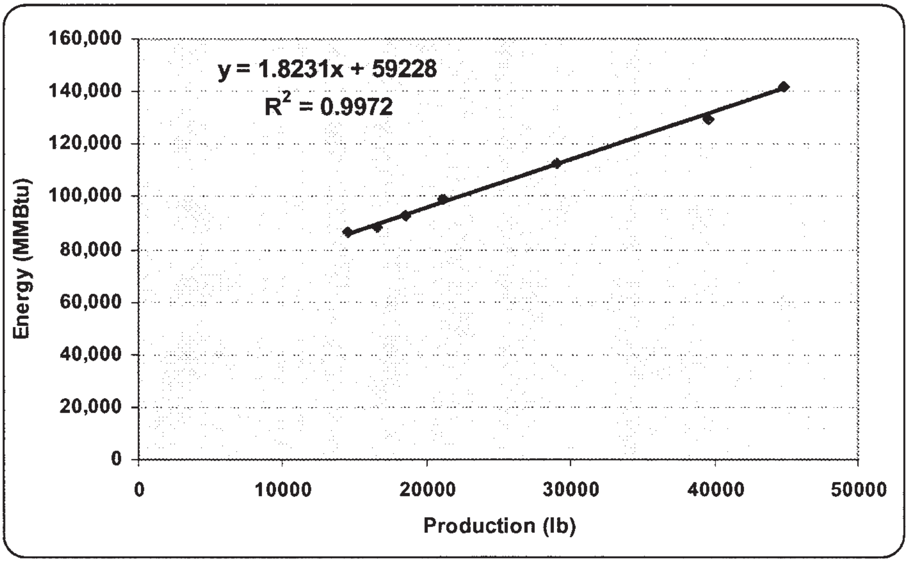

**Figure 1-23. Regression for Months 18-24**

The performance parameters for this period compared to the baseline period indicate the relative improvements:

**Table 1-9. Comparison of Peak Performance Period to Baseline Period**

| *Parameter* | *Baseline* | *Months 18-24* | *% Improvement* |
|---|---|---|---|
| Slope—production related consumption | 2.0078 | 1.8231 | 9.20 |
| Intercept—production unrelated consumption | 64,966 | 59,228 | 8.83 |

The improvement in the production-related consumption is 9.20%, while the production-unrelated baseload has been reduced by 8.83%. That is, there has been an improvement in operating efficiency as well as a reduction in baseload waste.

### 1.7.3 Setting Performance Targets

MT&R provides a statistical basis for setting performance targets. The parameters of the energy performance model typically quantify incremental and base loads, as seen above, and each of these components of load should be addressed separately.

Since an EPM can be defined for any period of historical performance, initial targets are often based on periods of peak performance. In the industrial example, a reasonable target is to sustain the performance of the 18- to 24-month period, as defined in Table 1-9.

Other strategies for setting targets include:

- **eliminating the highest or least efficient points** from the data set; in Figure 1-18, this would involve deleting the points that fall above the regression line from the data set and developing a new EPM on what remains;

- **defining best historical performance as the target;** in Figure 1-19, this would involve selecting only the points that fall well below the regression line and developing a new EPM on these points alone. This is equivalent to selecting the period of best performance on the CUSUM graph, as indicated above;

- **assessing the base and incremental loads** to identify specific actions that can be taken to reduce them, and defining a new EPM that adjusts the incremental and base load parameters accordingly.

Whichever method is used, target setting should be viewed as a continuous improvement strategy in order to maximize and sustain savings.

### 1.7.4 Controlling Performance

Once a target has been set, the challenge is to manage performance to achieve and sustain that performance. Control charts similar to those used to manage other functions can be constructed from the energy monitoring analysis to control energy performance.

Using the production case to illustrate, the data of Table 1-8 can be re-examined, now in light of a target EPM. For example, the 18 to 24 month period, the shaded cells in Table 1-10, is a suitable initial target since it represents superior performance that has already been demonstrated. The EPM for this period has been determined to be:

$$\text{Process Energy (MMBtu)} = 1.8231 \times \text{Production} + 59{,}228 \qquad (1\text{-}9)$$

A new set of predicted energy consumption values can be calculated, the "target" consumption as shown in Table 1-10. The variance between actual and target consumption is then calculated; positive values indicate consumption above target, negative below. Control charts are a plot of variance from standard (not cumulative variance as in CUSUM). The variance values calculated in Table 1-10 are plotted in Figure 1-24, the control chart.

Control limits can be applied to the control chart as shown; in Figure 1-24 they are arbitrarily set at +/2,500. The upper and lower control limits may reflect knowledge about what variance is tolerable or reasonable in the system being controlled (in this case, it is the entire process operation). There are also statistical criteria for setting control limits; a good value for the control level is 1.4 times the average of the variances in the target period ignoring the signs, in this example, +/–1,250 (as calculated from Table 1-10 for the period June through December, 2003).

While the CUSUM graph can also be used to monitor performance into the future, the control chart is a tool that lends itself to production floor or mechanical room applications for real-time control. Where in the example the time increment for the analysis is monthly, the same approach can be applied on a daily, weekly, shift, or batch-by-batch basis.

### 1.7.5 Reporting

Reporting within a MT&R system has a number of functions:

- to create motivation for energy saving actions;
- to report regularly on performance;
- to monitor overall utility costs;
- to monitor cost savings.

Within most organizations, the need for the type of information generated by a monitoring and targeting system varies with level and responsibility. Typically as the need moves from the operational level in the plant or building operation to the senior management level the requirement for detail diminishes, as does the frequency of reporting.

Operations staff need energy control information to stimulate

## Table 1-10. Control Chart Calculations for Production Example

| *Month* | *Production lb.* | *Total Process Energy, MMBtu* | *Predicted Process Energy MMBtu* | *Variance Actual-Predicted MMBtu* | *CUSUM MMBtu* | *Target Process Energy MMBtu* | *Variance Actual-Target MMBtu* |
|---|---|---|---|---|---|---|---|
| Jan 02 | 39,600 | 137,243 | 144,476 | -7,233 | -7,233 | 131,423 | 5,820 |
| Feb 02 | 21,120 | 107,620 | 107,371 | 248 1 | -6,985 | 97,732 | 9,888 |
| Mar 02 | 15,840 | 94,63-0 | 96,770 | -2,140 | -9,125 | 88,106 | 6,524 |
| Apr 02 | 13,200 | 102,649 | 91,469 | 11,179 | 2,054 | 83,293 | 19,356 |
| May 02 | 44,880 | 152,845 | 155,077 | -2,233 | -178 | 141,049 | 11,796 |
| Jun 02 | 47,520 | 171,792 | 160,378 | 11,414 | 11,235 | 145,862 | 25,930 |
| Jul 02 | 31,680 | 126,754 | 128,574 | -1,820 | 9,416 | 116,984 | 9,771 |
| Aug 02 | 10,560 | 84,905 | 86,169 | -1,263 | 8,152 | 78,480 | 6,426 |
| Sep 02 | 29,040 | 120,510 | 123,273 | -2,763 | 5,389 | 112,171 | 8,339 |
| Oct 02 | 23,760 | 108,051 | 112,672 | -4,621 | 768 | 102,545 | 5,556 |
| Nov 02 | 10,560 | 87,491 | 86,169 | 1,322 | 2,090 | 78,480 | 9,011 |
| Dec 02 | 13,200 | 89,379 | 91,469 | -2,090 | -0 | 83,293 | 6,086 |
| Jan 03 | 36,960 | 131,255 | 139,175 | -7,921 | -7,921 | 126,610 | 4,645 |
| Feb 03 | 40,920 | 144,886 | 147,126 | -2,240 | -10,161 | 133,829 | 11,057 |
| Mar 03 | 43,560 | 145,882 | 152,427 | -6,545 | -16,706 | 138,642 | 7,240 |
| Apr 03 | 50,160 | 158,760 | 165,679 | -6,919 | -23,625 | 150,675 | 8,086 |
| May 03 | 10,560 | 81,102 | 1 86,169 | -5,067 | -28,691 | 78,480 | 2,622 |
| Jun 03 | 14,520 | 86,234 | 94,120 | -7,886 | -36,577 | 85,699 | 535 |
| Jul 03 | 39,600 | 129,613 | 144,476 | -14,863 | -51,440 | 131,423 | -1,810 |
| Aug 03 | 21,120 | 98,710 | 107,371 | -8,661 | -60,101 | 97,732 | 979 |
| Sep 03 | 16,632 | 88,233 | 98,360 | -10,127 | -70,228 | 89,550 | -1,317 |
| Oct 03 | 29,040 | 112,643 | 123,273 | -10,630 | -80,858 | 112,171 | 472 |
| Nov 03 | 18,480 | 92,912 | 102,071 | -9,159 | -90,018 | 92,919 | -7 |
| Dec 03 | 44,880 | 142,198 | 155,077 | -12,879 | -102,897 | 141,049 | 1,149 |
| Jan 04 | 50,160 | 147,453 | 165,679 | -18,226 | -121,123 | 150,675 | -3,222 |
| Feb 04 | 42,240 | 147,231 | 149,777 | -2,546 | -123,669 | 136,236 | 10,995 |
| Mar 04 | 31,680 | 123,359 | 128,574 | -5,215 | -128,884 | 116,984 | 6,376 |

specific energy savings actions; while senior managers need summary information with which to guide the organization's energy management effort. This is depicted in Figure 1-25. One report for all will not result in the appropriate decisions being made, and actions being taken.

The format of the reports is unique to each organization. In general, reporting of information should be integrated into the organizational management information system.

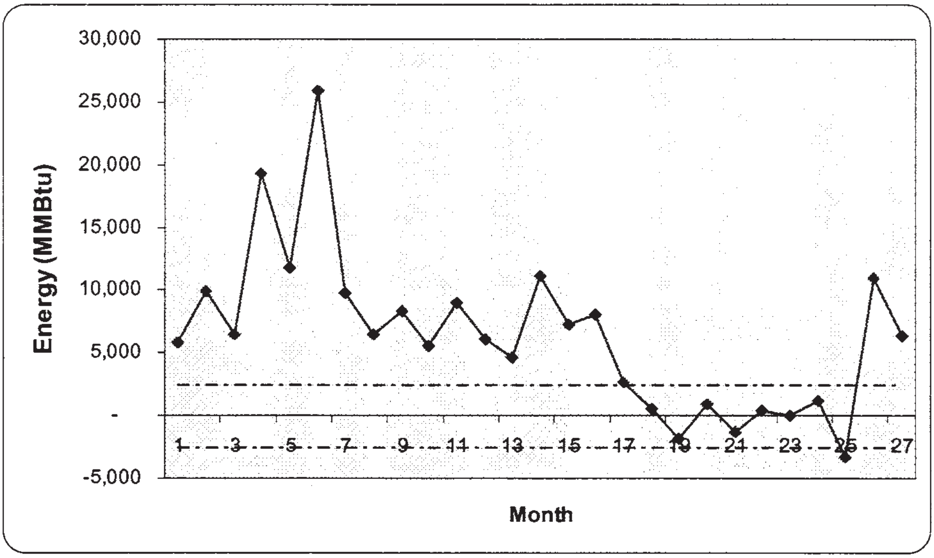

Figure 1-24. Control Chart for Production Example

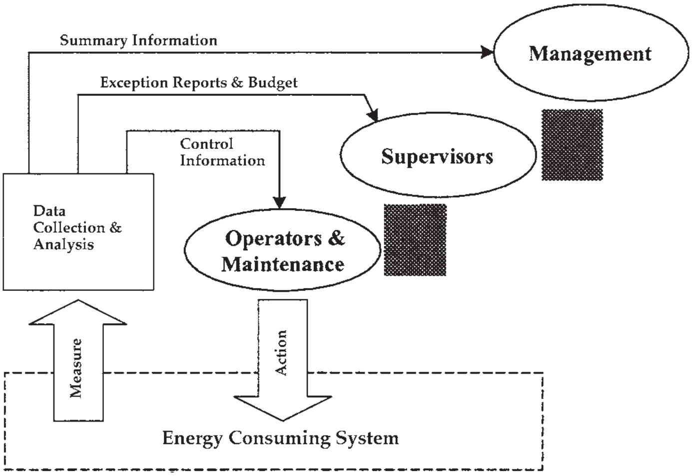

Figure 1-25. Reporting Pathways for a MT&R System

### 1.7.6 Savings Verification

There is a well-established protocol for verifying the savings that result from energy management measures. The IPMVP (International Performance Measurement and Verification Protocol) defines the fundamental relationship for comparing post-installation to pre-installation performance as:

$$\text{Savings} = (\text{Baseline Energy Use}_{\text{adjusted}} - (\text{Post-installation energy use})$$

The complicating factors are:

- what **adjustments** to the baseline performance are required, and how are they carded out;
- what **measurements** are required to determine post-installation performance, and how are they carried out.

The adjustment of baseline energy use is derived in part from the same energy performance model that is used to predict consumption for the purpose of monitoring and control. That is, adjustments need to account for varying weather factors (HDD and CDD), production, occupancy, and so on, just as was required for MT&R.

Organizations that routinely conduct MT&R are prepared to apply the same management information to the verification of savings resulting from energy management measures.

## 1.8 SUMMARY

This chapter has discussed the need for energy management, the historical use of energy, and the design, initiation, and management of energy management programs. The chapter emphasizes energy accounting, especially cost center accounting and necessary submetering.

We defined an energy management activity as any decision that involves energy and affects the profit level. Anything that improves profits and/or enhances competitive positions is considered effective energy management, and anything else is poor energy management. The motivation for starting energy management programs is multi-faceted and varies among companies. The following outline lists the major reasons:

- Economic—Energy management will improve profits and enhance competitive positions.

- National good—Energy management is good for the U.S. economy as the balance of payments becomes more favorable and the dollar stronger.

Energy management makes us less vulnerable to energy cutoffs or curtailments due to political unrest or natural disasters elsewhere.

Energy management is kind to our environment as it eases some of the strain on our natural resources and may leave a better world for future generations.

In designing an energy management program, several ingredients are vital:

- Top Management commitment. Commitment from the top must be strong and highly visible.
- One-person responsibility. The responsibility for the energy management program must lie in one person who reports as high in the organization structure as possible.
- Committee backup. The energy management coordinator must have the support of two committees. The first is a steering committee, which provides direction for the program. The second is a technical committee, which provides technical backup in the necessary engineering disciplines.
- Reporting and monitoring. An effective monitoring and reporting system for energy consumption must be provided.
- Training. Energy management is a unique undertaking. Hence, training and retraining at all levels is required.

To successfully start an energy management program, some publicity must accompany the early stages. This can be achieved with news releases, films, plant meetings, or a combination of them. Early project selection is a critical step. Early projects should be visible, and should have good monetary returns, with few negative consequences.

Management and creative personnel are always critical components of an energy management program. Tough, specific, and measurable goals need to be developed. Once the goals are established, management should carefully monitor the results, but the energy management staff should be allowed to perform its functions. Staff and management need to realize that (1) energy costs, not consumption, are to be controlled (2) energy should be a direct cost—not an overhead item, and (3) only the main energy consumers need be metered and monitored closely.

Energy accounting is the art and science of tracing Btu and energy dollar flow through an organization. Cost center orientation is important, as are comparison to some standard or base and calculations of variances. Causes for variances must then be sought. General Motor's energy responsibility accounting system was discussed in some detail. However, no accounting system is a panacea, and any system is only as accurate as the metering and reporting systems allow it to be.

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## Chapter 2

# The Energy Audit Process: An Overview

### 2.0 INTRODUCTION

Once a commercial or industrial facility has designated its energy manager and given that person the support and authority necessary to develop an adequate energy management program, the first step the energy manager should take is to conduct an energy audit. Also called an energy survey, energy analysis, or energy evaluation, the energy audit examines the ways energy is currently used in that facility and identifies some alternatives for reducing energy costs. The goals of the audit are:

- to clearly identify the types and costs of energy use,
- to understand how that energy is being used—and possibly wasted,
- to identify and analyze alternatives such as improved operational techniques and/or new equipment that could substantially reduce energy costs*, and
- to perform an economic analysis on those alternatives and determine which ones are cost-effective for the business or industry involved.

This chapter addresses the three phases of an energy audit: preparing for the audit visit; performing the facility survey and implementing the audit recommendations. In the first phase, data from the energy bills are analyzed in detail to determine what energy is being used and how the use varies with time. Preliminary information on the facility is compiled, the necessary auditing tools are gathered, and an audit team is assembled.

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*In most cases the energy cost savings will result from reduced consumption, but occasionally a cost savings will be associated with increased energy use. For example, a thermal storage system for heating and/or cooling may save on electric bills, but may actually increase the use of electric energy due to the losses in the storage system. While the primary goal of energy management programs is to reduce energy costs, some proposed alternatives may not always produce greater energy efficiency. However, an overall improvement in a facility's energy efficiency should be the overriding goal for any company's energy management team.

Phase two starts after a safety briefing when the team performs a walk-through inspection, looking carefully at each of the physical systems within the facility and recording the information for later use. After the plant survey, the audit team must develop an energy balance to account for the energy use in the facility. Once all energy uses have been identified and quantified, the team can begin analyzing alternatives. The final step of phase two is the audit report which recommends changes in equipment, processes or operations to produce energy cost savings.

Phase Three—the implementation phase—begins when the energy manager and the facility management agree on specific energy savings goals and initiate some or all of the actions recommended to achieve those goals. Setting up a monitoring system will allow management to assess the degree to which the chosen goals have been accomplished and to show which measures have been successful and which have failed. The results of the monitoring should feed back to the beginning of the audit cycle and thus potentially initiate more analysis, implementation, and monitoring.

## 2.1 PHASE ONE—PREPARING FOR AN ENERGY AUDIT

The energy audit process starts with an examination of the historical and descriptive energy data for the facility. Specific data that should be gathered in this preliminary phase include the energy bills for the past twelve months, descriptive information about the facility such as a plant layout, and a list of each piece of equipment that significantly affects the energy consumption. Before the audit begins, the auditor must know what special measurement tools will be needed. A briefing on safety procedures is also a wise precaution.

### 2.1.1 Gathering Preliminary Data on the Facility

Before performing the facility audit, the auditors should gather information on the historical energy use at the facility and on the factors likely to affect the energy use in the facility. Past energy bills, geographic location, weather data, facility layout and construction, operating hours, and equipment lists are all part of the data needed.

#### 2.1.1.1 Analysis of Bills

The audit must begin with a detailed analysis of the energy bills for the previous twelve months. This is important for several reasons: the bills show the proportionate use of each different energy source when compared to the total energy bill; an examination of where energy is used can point out previously unknown energy wastes; and, the total amount spent on energy puts an obvious upper limit on the amount that can be saved. The data from the energy bills can be conveniently entered onto a form such as shown in Figure 2-1. Note that the most significant billing factors are shown, including peak demand for electricity.

Location/Meter # ______________________________

From ______________ to ______________
(Mo./Yr.) (Mo./Yr.)

| Electrical use | | | | Gas use | | | Fuel oil | |
|---|---|---|---|---|---|---|---|---|
| Month | Peak kW | Usage: kWh | Cost | MMCF[a] | Dth[b] | Cost | Gallons | Cost |
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |

[a]1 MMCF = $10^6$ $ft^3$
[b] 1Dth = 10 therms = $10^6$ Btu

**Figure 2-1. Summary Form for Energy Use**

The energy bill data must be analyzed by energy source and billed location. The data can be tabulated as illustrated in Figure 2-2 of Example 2-1.

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**Example 2-1.** This example demonstrates the importance of analyzing energy bills. As Figure 2-2 shows, most of the gas used at this facility is used by the main heating plant. Therefore most of the energy management effort and money should be concentrated on the main heating plant.

| Building | Energy Costs | Percentage of total |
|---|---|---|
| Heating plant | $38,742.34 | 83.2% |
| East dormitory | 4,035.92 | 8.7% |
| Married student apartments | 1,370.79 | 2.9% |
| Undergraduate dormitory | 768.42 | 1.7% |
| Greenhouse | 560.21 | 1.2% |
| Child development center | 551.05 | 1.2% |
| President's home | 398.53 | 0.9% |
| Art barn | 104.77 | 0.2% |

**Figure 2-2. Natural Gas Bills for a Small College**

The data in this example should raise some questions for the auditor before he ever visits the facility. The greenhouse appears to use a lot of energy; it uses more than the child development center and almost as much as the undergraduate dormitory. Since the greenhouse is not particularly large, these data raised a red flag for the energy auditor. Because one should never make assumptions about what is actually using the energy, the auditor checked the gas consumption meter at the greenhouse to make sure it was not measuring gas consumption from somewhere else as well. Subsequent investigation revealed that the heating and cooling in the greenhouse were controlled by different thermostats. One thermostat turned the cooling on when the temperature got too high—but before the second thermostat had turned the heat off! If it had turned out that the gas use from several other buildings had been metered by the same meter as the greenhouse, it would have been necessary to find a way to allocate gas consumption to each building.

In this example, the amount of energy used in the president's house could also be questioned; it uses nearly as much gas as the child development center. Perhaps the president's home is used for activities that would warrant this much gas use, but some equipment problem might also be causing this difference, so an energy audit of this facility might be worthwhile.

Another way to present the data is in graph form. A sample of the type of graph that should be made for each type of energy is shown in Figure 2-3. Each area of the country and each different industry type has a unique pattern of energy consumption, and presenting the data as shown in Figure 2-3 helps in defining and analyzing these patterns. In the facility from which this example came, natural gas is used in the winter for space heating, so the January peak is not surprising. For electrical consumption, if a peak demand charge is based on the *annual* peak, the energy auditor must know the time and size of this peak in order to address measures to reduce it.

A complete analysis of the energy bills for a facility requires a detailed knowledge of the rate structures in effect for the facility. To accurately determine the costs of operating individual pieces of equipment, the energy bills must be broken down into their components, such as demand charge and energy charges for the electric bill. This breakdown is also necessary to be able to calculate the savings from Energy Management Opportunities (EMOs) such as high-efficiency lights and high-efficiency motors, and off-peak electrical use by rescheduling some opera-