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IEEE Recommended Practice for Energy Management in Industrial and Commercial Facilities

Sponsor
**Energy Systems Committee
of the
Industrial and Commercial Power Systems Department
of the
IEEE Industry Applications Society**

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Abstract: This recommended practice serves as an engineering guide for use in electrical design for energy conservation. It provides a standard design practice to assist engineers in evaluating electrical options from an energy standpoint. It establishes engineering techniques and procedures to allow efficiency optimization in the design and operation of an electrical system considering all aspects (safety, costs, environment, those occupying the facility, management needs, etc.).

Keywords: break-even analysis; cogeneration; demand control; electrical energy; electric rate structure; energy audit; energy balance; energy conservation program; energy monitoring; energy-rate method; energy savings; heating, ventilating, and air conditioning (HVAC); levelized cost analysis; life cycle costing (LCC); lighting; load management; load type; loss evaluation; marginal cost analysis; metering; power bill; process energy; process modification; product energy rate; space conditioning; utility rate structure

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Introduction

(This introduction is not a part of IEEE Std 739-1995, IEEE Recommended Practice for Energy Management in Industrial and Commercial Facilities.)

IEEE Std 739-1984, IEEE Recommended Practice for Energy Conservation and Cost-Effective Planning in Industrial Facilities, was the precursor to this revision. That publication was born out of a need to convey conservation techniques to electrical engineers, designers, and operators. Much had been written for mechanical and architectural engineers at that point in time, but little had been written and disseminated to electrical engineers.

This new version has changed in several ways and has added new material that is the result of a decade of research and innovation by IEEE and others. The most obvious change is the title of this standard, “IEEE Recommended Practice for Energy Management in Industrial and Commercial Facilities.” The title shows a recognition of the need to manage a valuable resource—electrical energy. The title change also shows an expansion of scope. The scope expansion resulted when the parent committee sponsoring the work changed to the Energy Systems Committee. The Energy Systems Committee is one of five main technical committees in the Industrial and Commercial Power Systems Department of the IEEE Industry Applications Society. This new sponsorship expanded the focus of this recommended practice to include commercial facilities.

We are thankful to those who have given time and effort to the birthing of this recommended practice and who are no longer members of this committee. In particular, John Linders, Mel Chiogioji, Art Killin, H. L. (Sonny) Harkins, and Terry McGowan should be remembered as pioneers in the establishment of this recommended practice.

This IEEE recommended practice continues to serve as a companion publication to the following other recommended practices prepared by the IEEE Industrial and Commercial Power Systems Department:

- IEEE Std 141-1993, IEEE Recommended Practice for Electric Power Distribution for Industrial Plants (IEEE Red Book).
- IEEE Std 142-1991, IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems (IEEE Green Book).
- IEEE Std 241-1990, IEEE Recommended Practice for Electric Power Systems in Commercial Buildings (IEEE Gray Book).
- IEEE Std 242-1986 (Reaff 1991), IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems (IEEE Buff Book).
- IEEE Std 399-1990, IEEE Recommended Practice for Industrial and Commercial Power Systems Analysis (IEEE Brown Book).
- IEEE Std 446-1995, IEEE Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications (IEEE Orange Book).
- IEEE Std 493-1990, IEEE Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems (IEEE Gold Book).
- IEEE Std 602-1996, IEEE Recommended Practice for Electric Systems in Health Care Facilities (IEEE White Book).
- IEEE Std 1100-1992, IEEE Recommended Practice for Powering and Grounding Sensitive Electronic Equipment (IEEE Emerald Book).

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IEEE Recommended Practice for Energy Management in Industrial and Commercial Facilities

Chapter 1

Overview

1.1 Scope

This IEEE recommended practice was conceived in the early 1970s shortly after the oil embargo. The purpose was to publish an engineering guide for use in electrical design for energy conservation. The purpose of this recommended practice continues to be one of providing a standard design practice to assist engineers in evaluating electrical options from an energy standpoint. Hence, it is a recommended practice for energy management in design and operation of an electrical system.

This recommended practice is not intended to be one to set minimum values for regulatory (law making) purposes. The intent is rather to establish engineering techniques and procedures to allow efficiency optimization in the design and operation of an electrical system considering all aspects (safety, costs, environment, those occupying the facility, management needs, etc.). Other national standards are mentioned where applicable for reference by the reader. State and local governments usually adopt some or all of these national standards, which makes them law, and on occasion, the governing body prepares its own standard(s).

1.2 General discussion

IEEE Std 739-1995, IEEE Recommended Practice for Energy Management in Industrial and Commercial Facilities (commonly known as the IEEE Bronze Book) is published by the Institute of Electrical and Electronics Engineers (IEEE) to provide a recommended practice for electrical energy management in industrial and commercial facilities. It has been prepared by engineers and designers on the Energy Systems Committee of the IEEE Industrial and Commercial Power Systems Department (ICPS) with the assistance of the Production and Application of Light Committee (PAL).

This recommended practice will probably be of greatest value to the power-oriented engineer with some design or operation experience with industrial and commercial facilities. It can be an aid, however, to engineers and designers at

all levels of experience. It should be considered a guide and reference rather than a detailed manual, to be supplemented by the many excellent publications available.

There will be an overlap with other fields of engineering, particularly mechanical and architectural, in the area of building systems, which are covered in this recommended practice.

When references are made to codes, standards, laws, and regulations, it is essential that the document referred to or current authentic interpretation be consulted. Such material changes frequently in contrast to conventional engineering information, and it is impractical to include complete current regulations or detailed interpretations in a text of this size.

1.3 Management

Energy management embodies engineering, design, applications, utilization, and to some extent the operation and maintenance of electric power systems to provide for the optimal use of electrical energy. *Optimal* in this case refers to the design or modification of a system to use minimum overall energy where the potential or real energy savings are justified on an economic or cost benefit basis. Optimization also involves factors such as comfort, healthful working conditions, the practical aspects of productivity, aesthetic acceptability of the space, and public relations.

Energy management involves the following professions and fields:

- Engineering
- Management
- Economics
- Financial analysis
- Operations research (system analysis)
- Public relations (selling conservation)
- Environmental engineering

Some of the tools that are utilized include the following:

- Meters and measurement
- Demand and energy limiters
- Highly efficient energy devices
- Control systems (e.g., building management systems)

While this recommended practice emphasizes electrical energy management, other forms of energy are also discussed. Chapter 8 covers the combined efficient use of electrical and thermal energy (steam) in a highly efficient and cost-effective manner. Chapter 2 points out that the reduction of energy in one area can have a negative effect on energy needs in another area. For example, the reduction of lighting levels in large buildings in winter can cause increased operation of the heating system because of the loss of heat from the lamps and ballasts.

1.4 Fuel cost effects on electrical energy

Since fuel cost impacts the cost of electrical energy, this subclause discusses the factors that affect the costs of today's major fuels.

All known fuels or energy sources have a life cycle that begins with the development of a means to effectively manufacture and utilize the fuel itself. The energy source then grows in usage to a point of maximum production at which the usage begins to decline. This decline is caused by many factors, including obsolescence and depletion of supply. Today's energy sources can be divided into three major categories: fossil, solar, and nuclear fuels.

1.4.1 Fossil fuel

The three most common fossil fuels are coal, natural gas, and oil. Their cleanliness, heat content, and availability will affect their use and electrical costs in the future, so these aspects are covered in this subclause.

- a) Coal is generally acknowledged as the most plentiful fossil fuel resource in the U.S. At current consumption rates, the supply should last at least 100 years. The Btu content and quality of coal varies from region to region, and it is not uniformly available throughout the country. Problems affecting the use and availability of coal are: mining, including site restoration and water pollution; transportation; air pollution; and lack of a coherent governmental coal-burning policy that encourages the use of this resource. However, industry and government continue to fund programs for clean coal burning research. Some new techniques are being tested for the use of coal, and new coal burning technologies should be available in the coming years. One advantage of coal as an energy source is that the industry is unregulated. This fact makes coal costs subject, to some extent, to the laws of supply and demand. However, government health and safety mining regulations, in addition to inflationary pressures and the energy situation in general, have caused coal prices to soar. Coal prices should track inflation under the present conditions.
- b) Natural gas is the cleanest burning fossil fuel, but it has the least proven reserves. Natural gas presents few air pollution problems and is probably the least capital intensive of the fossil fuels. Questionable availability remains its chief disadvantage, although deregulation has encouraged exploration and the use of wells that were previously thought to be uneconomical to operate. In summary, gas prices should rise at the rate of inflation, but deregulation could adversely affect the price if, at some point, the supply fails to keep pace with demand.
- c) Oil is the second cleanest burning fuel, and it is not very capital intensive when compared to coal. Because of these two factors, it has distinct advantages as an industrial and commercial fuel. Availability could be a future problem. As long as the U.S. imports oil there should be few problems with availability. The price of domestic oil was regulated by the Federal government and is now in the process of deregulation, while the world price of oil is unregulated. The problems caused by the oil embargo of 1973 and the Iraq conflict are well documented. In summary, the price of foreign oil has no relationship to the laws of supply and demand. The U.S. demand for oil has outstripped our domestic supply. Without foreign oil, we would deplete our reserves in approximately two decades. The U.S. is confronted, therefore, with a problem concerning the use of oil now and in the immediate future. Oil prices will continue to fluctuate due to world market changes.

1.4.2 Solar fuel

Solar energy encompasses the use of the sun's radiation to produce electricity or as a direct source for heating and cooling. Solar energy has gained attention because of governmental and general public pressure due to its non-polluting characteristic.

Five primary types of solar energy are: photovoltaic, thermal, wind, hydropower, and biomass. Photovoltaic involves the direct conversion of the sun's rays into electricity. Thermal conversion uses the sun's rays to create heat, which is either used directly or to create steam for electric generation. Wind is generally used to provide shaft horsepower to a generator. Biomass primarily involves trash as a heat source for a steam-driven turbine generator.

- a) Photovoltaics are probably the most interesting means of converting solar energy into electricity. They have relatively poor efficiencies and cost several times more per kilowatthour than other methods. They can only generate electricity on sunny days. However, the strides in development have been great, and they will probably be a viable alternate in future years.
- b) Thermal conversion has not proven economical for generating electricity. However, heating and cooling systems are now marketed that compete favorably with other energy sources on a five- to ten-year payback basis. A central collector has been proposed for use in generating steam for a turbine-driven generator. However, the land requirement is large at over 150 acres per electric megawatt output, and the output is restricted to daylight hours.

- c) Wind conversion has been used successfully to generate electrical energy. Some disadvantages of wind generation include noise, radio and TV interference, very fast tip speeds (60–80 ft/s), and size limitation. However, there are areas of the country with typical wind speeds of 7–30 mi/h where windmill farms successfully generate bulk power.
- d) Most electricity generated today by hydropower is by high head dams, large scale operations that only large investors can afford to finance. However, low head dams are becoming more attractive as a means to generate electricity. The use of low head dams could improve the availability of electricity on a local basis.
- e) Biomass is being used in conjunction with other fuels, due to low heat content. This source may begin to supply small amounts of power for municipalities and industrial complexes. As with coal, there are many pollution and handling problems.

1.4.3 Nuclear fuel

There are three nuclear conversion techniques: fission, breeder, and fusion reactors. While this is the cleanest and most economical source of power, regulations and political pressures make future dependence on this source questionable. Fission conversion has proven economical for three to four decades. However, the disposal of nuclear waste and eventual plant decommissioning methods have not received universal concurrence. Furthermore, the known uranium reserve would only supply energy for 100 years to a nation totally reliant on fission power.

The breeder reactor can multiply the nuclear supply by a factor of ten by recycling nuclear waste. This concept has been demonstrated on a large scale, but development in the U.S. has been virtually at a standstill.

The fusion concept has been sustained on a laboratory level, but full development is not anticipated for decades. Fusion could ultimately provide a virtually unlimited supply of energy at a very low cost without pollution. However, the infancy of fusion technology makes this source inappropriate for consideration at this time.

From all indications, the cost of electricity will increase at a rate at least equal to that of annual inflation. Coal will probably be the primary source of fuel in the U.S. Petroleum and gas will probably increase in price at a rate faster than electricity, but the relative costs and rates will differ in various areas.

1.5 Periodicals

The energy engineer needs to keep up-to-date on new technologies in this rapidly expanding field. The following periodicals offer new engineering information on energy conservation.

- a) *Spectrum*, the monthly magazine of the IEEE, covers all aspects of electrical and electronics engineering, including conservation. It contains references to IEEE books and other publications; technical meetings and conferences; IEEE group, society, and committee activities; abstracts of papers and publications of the IEEE and other organizations; and other material essential to the professional advancement of the electrical engineer.
- b) *IEEE Transactions on Industry Applications* contains papers presented to conferences, a number of which include the subject of energy management. All members of the Industry Applications Society (IAS) receive this publication.
- c) Publications that are specifically oriented toward energy conservation include:
 - 1) *Energy User News*¹ is a monthly news publication in tabloid format that covers the entire field of energy conservation with emphasis on keeping the reader informed of new technologies. It is quite open in discussing the effectiveness or failures of systems. A legislative and regulatory scoreboard² is included.
 - 2) *NTIS*, the National Technical Information Service of the U.S. Department of Commerce,² is an abstract newsletter published weekly. It contains abstract of hundreds of articles relating to energy, listed by subject. An order form for purchasing many of the articles is included with each issue.

¹ Radnor, PA.

² 5285 Port Royal Road, Springfield, VA 22161.

- d) The Association of Energy Engineers³ publishes several documents including the bimonthly *Energy Engineering* and the quarterly *Strategic Planning for Energy and the Environment*. In addition, the Association sponsors conferences.
- e) Some other periodicals of a more general nature that are heavily involved with electrical energy conservation are as follows:
 - 1) *Electrical Construction and Maintenance*, 1221 Avenue of the Americas, New York, NY 10020.
 - 2) *Electrical Consultant*, One River Road, Cos Cob, CT 06807.
 - 3) *LD & A*, Illuminating Engineering Society, 345 East 47th Street, New York, NY 10017.
 - 4) *Plant Engineering*, 1350 Touhy Avenue, P. O. Box 5080, Des Plaines, IL 60017-5080.
 - 5) *Power*, 1221 Avenue of the Americas, New York, NY 10020.
 - 6) *Power Engineering*, 1301 South Grove Avenue, Barrington, IL 60010.
 - 7) *Electric Light and Power*, 1301 South Grove Avenue, Barrington, IL 60010.
 - 8) *Consulting-Specifying Engineer*, 44 Cook Street, Denver, CO 80206-5800.
- f) Two technical periodicals that contain material of interest are as follows:
 - 1) *Energy Management* is directed at management in business and industry. It is published bimonthly by Penton, 614 Superior Avenue West, Cleveland, OH 44113.
 - 2) *Plant Energy Management* is published bimonthly by Walker-Davis Publication, Inc., 2500 Office Center, Willow Grove, PA 19090.

It should be noted that new periodicals can be expected in the expanding field of energy. Some of the publications are available at no cost to qualified individuals engaged in energy management work.

1.6 Standards and Recommended Practices

A number of organizations in addition to the National Fire Protection Association (NFPA)⁴ publish documents that affect electrical design. Required adherence to these documents can be written into design specifications.

- a) The American National Standards Institute (ANSI)⁵ coordinates the review of proposed standards among all interested affiliated societies and organizations to ensure a consensus approval. It is in effect the clearing house in the U.S. for technical standards of all types.
- b) Underwriters' Laboratories, Inc. (UL)⁶ is a nonprofit organization, operating laboratories for investigation of materials and products, especially electrical appliances and equipment with respect to hazards affecting life and property.
- c) The Edison Electric Institute (EEI) and the Electric Power Research Institute (EPRI) represent the investor-owned utilities and publish extensively. The following handbooks are available through EEI:⁷
 - 1) *Electrical Heating and Cooling Handbook*
 - 2) *A Planning Guide for Architects and Engineers*
 - 3) *A Planning Guide for Hotels and Motels*
 - 4) *Electric Space-Conditioning*
 - 5) *Industrial and Commercial Power Distribution*
 - 6) *Industrial and Commercial Lighting*
- d) The National Electrical Manufacturer's Association (NEMA)⁸ represents equipment manufacturers. Their publications standardize the manufacture of, and provide testing and operating standards for, electrical equipment. The design engineer should be aware of any NEMA standard that might affect the application of any equipment that he or she specifies.

³ 4025 Pleasantdale Road, Suite 420, Atlanta GA 30340.

⁴ 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101.

⁵ 11 West 42nd St., New York, NY 10036.

⁶ 333 Pfingsten Road, Northbrook, IL 60062.

⁷ 701 Pennsylvania Ave., N.W., Washington, DC 10004-2696.

⁸ 1300 17th St., Suite 1847, Rosslyn, VA 22209.

- e) The IEEE publishes several hundred electrical standards relating to safety, measurements, equipment testing, application, and maintenance. The following three publications are general in nature and are important for the preparation of plans:
 - 1) IEEE Std 100-1992, The New IEEE Standard Dictionary of Electrical and Electronics Terms (AN SI).
 - 2) IEEE Std 315-1975 (Reaff 1993), IEEE Standard Graphic Symbols for Electrical and Electronics Diagrams, and IEEE Std 315A-1986 (Reaff 1993), Supplement to IEEE Std 315-1975 (ANSI).
 - 3) IEEE Std Y32.9-1972 (Reaff 1989), American National Standard Graphic Symbols for Electrical Wiring and Layout Diagrams Used in Architecture and Building Construction.
- f) The Building Officials and Code Administrations International, Inc. (BOCA®)⁹ is an organization that promulgates the BOCA building construction model codes. It also provides educational services in code administration and enforcement. Many governmental bodies have mandated its codes as the governing construction code. They published the BOCA National Energy Conservation Code of 1993.
- g) The Council of American Building Officials (CABO)¹⁰ published the “Model Energy Code” in 1992 with input from several organizations: Building Code Officials and Code Administrators International, Inc. (BOCA); International Conference of Building Officials (ICBO); National Conference of States on Building Codes and Standards (NCSBCS); and Southern Building Code Congress International, Inc. (SBCCI).

1.7 Industry Applications Society (IAS)

The IAS is one of 37 IEEE groups and societies that specialize in various technical areas of electrical and electronics engineering. Each group or society conducts meetings and publishes papers on developments within its specialized area. Some of the more relevant technical committees include the Petroleum and Chemical Industry, the Cement Industry, the Glass Industry, and the Industrial and Commercial Power Systems Committees. Papers of interest to electrical engineers and designers involved in the fields covered by the IEEE Bronze Book are, for the most part, contained in the *IEEE Transactions on Industry Applications*.

1.8 IEEE publications

The IEEE Bronze Book is one of a series of standards that are published by IEEE and are known as the IEEE Color Books. These standards are prepared by the Industrial and Commercial Power Systems Department of the IEEE Industry Applications Society.¹¹ They are as follows:

- IEEE Std 141-1993, IEEE Recommended Practice for Electric Power Distribution for Industrial Plants (IEEE Red Book).
- IEEE Std 142-1991, IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems (IEEE Green Book).
- IEEE Std 241-1990, IEEE Recommended Practice for Electrical Power Systems in Commercial Buildings (IEEE Gray Book).
- IEEE Std 242-1986 (Reaff 1991), IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems (IEEE Buff Book).
- IEEE Std 399-1990, IEEE Recommended Practice for Industrial and Commercial Power System Analysis (IEEE Brown Book).
- IEEE Std 446-1987, IEEE Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications (IEEE Orange Book).
- IEEE Std 493-1990, IEEE Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems (IEEE Gold Book).
- IEEE Std 602-1996, IEEE Recommended Practice for Electric Systems in Health Care Facilities (IEEE White Book).¹²

⁹94051 West Flossmoor Road, Country Club Hills, IL 60478-5795.

¹⁰4205 Leesburg Pike, Falls Church, VA.

¹¹IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331.

- IEEE Std 739-1995, IEEE Recommended Practice for Energy Management in Industrial and Commercial Facilities (IEEE Bronze Book).
- IEEE Std 1100-1992, IEEE Recommended Practice for Powering and Grounding Sensitive Electronic Equipment (IEEE Emerald Book).

1.9 Governmental regulatory agencies

- a) Actions of the U.S. government regulatory agencies are embodied in the *Federal Register*.¹³ Often the rules have sufficient legal complexity that interpretations are best left to experts in the field. The agencies making such rules shall operate within the scope of laws enacted by Congress.
- b) The Department of Energy (DOE) sponsors experimental or demonstration projects through grants and other incentives. Reports are issued on programs such as the fluorescent lamp solid-state ballast under grant to Lawrence Berkeley Laboratories of the University of California.
- c) Some individual states have their own Departments of Energy. Agencies such as the DOE are able to exert a powerful influence on these local departments through law or by the ability to withhold funds for areas deemed not in compliance with federal regulations. At the present time, ASHRAE/IESNA 90.1-1989¹⁴ is accepted as a basis for design of new and existing commercial buildings. While some states have accepted these standards almost verbatim, a few other states have issued their own equivalents. It is important to recognize which rulings are based on law in the locality under consideration.
- d) ASHRAE/IESNA 90.1-1989, Energy Efficient Design of New Buildings Except Low-Rise Residential Buildings, was developed by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) in conjunction with members of the Illuminating Engineering Society of North America (IESNA). The production of this recommended practice was encouraged by various governmental agencies to fill a need for a standard developed on a consensus basis by voluntary professional organizations knowledgeable in energy conservation. However, this and other standard documents have legal status only where local authorities have incorporated their recommendations in law.
- e) Where generation (except for emergency and standby purposes) is involved and especially where the resale and redistribution of energy for use by others is concerned, regulations of the Federal Energy Regulatory Commission (FERC) may apply. PURPA, the Public Utility Regulatory Policies Act of 1978, provides guidelines for the sale and resale of energy and for exemption from FERC rulings, which are applicable to utilities. Industries employing cogeneration or generation not requiring fossil fuels fall under PURPA jurisdiction. These industries are exempt from certain FERC regulations. They also have certain advantages in their relations with utility companies.
- f) Public Service Control Boards or Utility Regulatory Commissions govern the actions of the local utilities. They enact rules and establish rates, after public hearings, responsive to the needs of the utilities and their customers and to the pressures of governmental bodies as described above. During recent years, these Commissions have recognized energy conservation needs by establishing time of day, incremental, cogeneration, and similar rates intended to minimize energy and peak demand power usage. The effects of such actions are expressed in the rates and rules of the local utilities.
- g) Utilities usually provide energy conservation services in addition to their more conventional advice on rates and conditions of service. Some utilities will provide energy audits and some may be required to check the energy budget before providing service. However, the advice they provide is usually more general than that of the consultant or in-house engineer.

1.10 Keeping informed

The following suggestions offer ways to remain current amid the abundance of information being generated in the energy field:

¹²As this standard goes to press, IEEE Std 602-1996 is approved but not yet published. The draft standard is, however, available from the IEEE. Anticipated publication date is March 1997. Contact the IEEE Standards Department at 1 (908) 562-3800 for status information.

¹³This daily publication is available from the U.S. Government Printing Office, Washington DC 20402.

¹⁴ASHRAE publications are available from the Customer Service Dept., American Society of Heating, Refrigerating and Air-Conditioning Engineers, 1791 Tullie Circle, NE, Atlanta, GA 30329.

- a) Read the aforementioned periodicals. Some are dedicated to energy only, while others can be scanned for energy articles.
- b) Attend energy-oriented conferences and courses, hundreds of which are given throughout the country. The courses are often conducted for one or two days and may cover the subject in general or concentrate on special aspects.
- c) Become active in the energy committees of societies such as the IEEE, IESNA, AIA (American Institute of Architects),¹⁵ and ASHRAE on a local or national basis.
- d) Read professional books and handbooks dealing with conservation. These will often be advertised or listed in the periodicals referred to above.
- e) Read advertising literature, which, although often biased, can provide an excellent guide to new equipment, its application, and the basis of justification.
- f) If you are a manager, establish the programs described in the following chapters, utilize the services of consultants, and attend energy seminars specifically designed for the manager, executive architect, financial planner, etc.

1.11 Professional activities

If an engineer is to practice publicly, professional registration is often required. Many organizations require such registration for certain levels of engineering. Regulatory agencies require that designs for public and commercial buildings be prepared under the jurisdiction of state-licensed professional architects or engineers. Information on such registration may be obtained from the appropriate state agency or from the local chapter of the National Society of Professional Engineers.

To facilitate obtaining registration in different states under the reciprocity rule, a National Professional Certificate is issued by the Records Department of the National Council of Examiners for Engineering and Surveying (NCEE)¹⁶ to engineers who obtained their homestate license by examination. All engineering graduates are encouraged to start on the path to full registration by taking the engineer-in-training examination as soon after graduation as possible. The final written examination in the field of specialization is usually conducted after four years of progressive professional experience.

1.12 Coordination with other disciplines

During the course of work, the energy engineer will often span several of the conventional disciplines and will often work with engineers from other disciplines.

The energy engineer is concerned with professional associates such as the architect, the mechanical engineer, the structural engineer, and, where underground services are involved, the civil engineer. The energy engineer is also concerned with the builder and the building owner or operator who, as clients, may take an active interest in the design or redesign. The energy engineer will work directly with the architect and will cooperate with the safety engineer, fire-protection engineer, environmental engineer, and a host of other concerned people, such as interior decorators, all of whom may have a say in the ultimate design or modification for conservation.

In performing conservation design, it is essential, at the outset, to prepare a checklist of all the design stages that have to be considered. Major items include staging, clearances, access to the site, and review by others. It is important to note that certain conservation work may appear in several chapters of the general construction specifications. Building control systems, even if electronically based, may appear in the mechanical section or in a separate section. Many organizations utilize the specification format of the Construction Specifications Institute (CSI)¹⁷ where the energy conservation work of the electrical-mechanical engineering will usually fall in Chapter 15, Chapter 16 (electrical), and (if included) Chapter 17 (special building control systems). For example, furnishing and connecting of chiller electric motors may be covered in the mechanical section of the specifications. For administrative purposes, the work may be

¹⁵ 1735 New York Ave. NW, Washington, DC 20006.

¹⁶ P.O. Box 1686, Clemson, SC 29633-1686.

¹⁷ 601 Madison Avenue, Industrial Park, Alexandria, VA 22314.

divided into a number of contracts, some of which may be awarded to contractors of different disciplines. The designer will be concerned with items such as preliminary estimates, final cost estimates, plans or drawings, specifications (which are the written presentation of the work), materials, manuals, factory inspections, laboratory tests, and temporary power. The designer may also be involved in providing information on how the proposed conservation items affect financial justification of the project in terms of owning and operating costs, amortization, return on investment, and related items

The energy engineer is encouraged to proceed with care in making changes that affect people. A test installation is often justified in determining the acceptability of an installation. Human reactions to changed environment often cannot be modified without considering the other physical factors. Some typical pitfalls are listed below.

- Are lighting color changes acceptable and compatible?
- Are workers uncomfortable in the changed ventilation conditions?
- Is task lighting producing a gloomy environment?
- Is machinery operating at reduced power because of voltage reduction in a brownout?
- Is the area uncomfortably humid because of loss of reheat?
- Is the building computer properly programmed and debugged?
- Is an otherwise perfectly good lighting redesign producing a rash of headache and eye complaints?
- Are the building tenants sharing in energy savings?

The experienced energy engineer will have encountered most of these conditions, which are covered in this text, and be able to avoid the possible negative side of energy conservation. A host of tools described in this recommended practice are available to ease the work of the engineer in preparing a well conceived, energy-conserving design.

1.13 Text organization

Subsequent chapters cover energy management in the following sequence of subjects:

Chapter 2: Organizing for energy management.

The proper organization and management commitment are prerequisites to a successful energy conservation effort.

Chapter 3: Translating energy into cost.

Several models for evaluating energy alternatives are provided, as well as a method for motor and transformer loss evaluation. Electric rate structures are explained.

Chapter 4: Load management.

The use of demand control can reduce electric bills but not necessarily energy use. Demand control techniques and, more importantly, energy control techniques, are discussed.

Chapter 5: Energy management for motors, systems, and electrical equipment.

Proper application of equipment along with correct design and maintenance of the electrical system and its components are key factors in energy conservation and system efficiency.

Chapter 6: Metering for energy management.

Proper measurement techniques ensure a viable and continually effective energy conservation program.

Chapter 7: Energy management for lighting systems.

New devices and proper application of existing equipment can provide significant energy savings.

Chapter 8: Cogeneration.

The concurrent use of steam (or other heat sources) for process (and comfort) heating, and electric generation provides a very efficient process, provided that specific requirements are met.

Design details are too intricate for discussion in this text. The reader is therefore advised to make extensive use of design manuals and other sources.

Chapter 2

Organizing for energy management

2.1 Introduction

To understand the energy consumption patterns in a facility, it is important to understand the applications of energy processes. Energy applications are grouped into six major types.

2.1.1 Types of energy applications

- a) *Space conditioning.* Energy used directly for heating or cooling an area for comfort conditioning.
- b) *Boiler fuel.* This is subdivided into space conditioning and process energy, depending on how the steam or hot water from the boiler is utilized.
- c) *Direct process heat.* Energy used to heat the product being processed, e.g., for kilns, reheat furnaces, etc., excluding energy used in boiler steam or hot water.
- d) *Feedstock.* Fuel used as an ingredient in the process, e.g., electroplating and sodium production.
- e) *Lighting.*
- f) *Mechanical drive.* Motors used for ventilation systems, pumps, crushers, grinders, production lines, etc. possess this mechanical drive.

Energy savings can result from improvements in the efficiency of the energy conversion processes, either by recycling waste energy or by reusing waste materials.

Any process requires a certain minimum consumption of energy. Energy (or equipment) additions beyond this minimum require an evaluation of the incremental cost of more efficient equipment or techniques versus the resulting energy savings or costs. Some of the more intensive users of industrial energy, including chemicals, paper, and petroleum refining, have long found it competitively advantageous to design for energy conservation. Virtually all new commercial/industrial facility designs consider energy conservation in some form.

Two economic incentives exist for the development of an energy management program on a facility-by-facility basis: savings realized by reducing energy use, and preventing economic losses by minimizing the probability of fuel supply curtailment.

With increasing costs of energy, every facility can benefit by seeking to reduce energy consumption.

2.1.2 Energy saving methods

The four general categories in which energy savings can be grouped are as follows:

- a) *Housekeeping measures.* Energy savings can result from better maintenance and operation. Such measures include shutting off unused equipment; improving electricity demand management; reducing winter temperature settings; turning off lights; and eliminating steam, compressed air, and heat leaks. Proper lubrication of equipment, proper cleaning and replacement of filters in equipment, and periodic cleaning and lamp replacement in lighting systems will result in optimal energy use in existing facilities.
- b) *Equipment and process modifications.* These can be either applied to existing equipment (retrofitting) or incorporated in the design of new equipment. Examples include the use of more durable or more efficient components; the implementation of novel, more efficient design concepts; or the replacement of an existing process with one using less energy.
- c) *Better utilization of equipment.* This can be achieved by carefully examining the production processes, schedules, and operating practices. Typically, industrial plants are multiunit, multiproduct installations that evolved as a series of independent operations with minimum consideration of overall plant energy efficiency.

Improvements in plant efficiency can be achieved through proper sequencing of process operations, rearranging schedules to utilize process equipment for continuous periods of operation to minimize losses associated with start-up; scheduling process operations during off-peak periods to level electrical energy demand; and conserving the use of energy during peak demand periods. Commercial facilities will typically achieve energy savings by relamping, installing adjustable speed drives in ventilation systems, and considering solar effects.

- d) *Reduction of losses in the building shell.* Reduction in heat loss is achieved by adding insulation, closing doors, reducing exhaust, utilizing process heat, etc.

Management should provide effective personnel motivation, planning, and administration to achieve meaningful energy savings. The establishment of a formalized energy management responsibility is highly desirable to give the effort both the focus and the direction required. An energy management function gives the line manager the tools to get the job done. Line managers need to know their energy use and costs, the future energy supply availability and its cost, problems or opportunities of energy situations, and those alternative solutions worth pursuing.

The following clauses attempt to identify and describe the steps needed to implement an effective energy management program. The engineer or plant manager can be a catalyst in developing a solid, functional energy management program.

2.2 Organizing the program

At any level of the corporate structure, an individual should understand the incentives and motivations of top management. An alert engineer will become aware of the hidden lines of authority and the key persons who make decisions. These key persons should be convinced of the positive merits of an energy management program before it can be successful. Therefore, it is the engineer's job to see that the proper facts are presented through the proper channels to convince top management that they should make the energy commitment. Sometimes the informal organizational structure is an effective tool.

The five critical factors in organizing an effective energy management program are as follows:

- a) *Obtain top management energy commitment.* This is a formally communicated, financially supported dedication to reducing energy consumption while maintaining or improving the functioning of a facility. This commitment shall be active and clearly and visibly communicated to all levels of the organization in terms of words and actions by top management.
- b) *Obtain people commitment.* People at all levels of the organization should be involved in the program. Ideas should be encouraged with rewards for significant contributions to the energy management program. People should be shown why their help is needed, and a team approach should evolve. The most successfully planned program can be devastated by a single person trying to subvert the program.
- c) *Set up a communication channel.* The purpose of this channel is to report to the organization the results of your efforts, to recognize high achievers, and to identify reward recipients. Use the channel to advertise the program and to encourage cooperation.
- d) *Change or modify the organization to give authority and commensurate responsibility for the conservation effort and develop an energy management program.*
- e) *Set up a means to monitor and control the program.*

An organizational plan, using the above criteria, should then be developed for both implementing and monitoring specific energy management programs. This plan should also define the responsibilities of the energy management coordinator or committee; describe an effective communication system between coordinator and major divisions, departments, and employees; establish an energy accounting and monitoring system; and provide the means for educating and motivating employees. Realistic goals should be established that are specific in both amount and time. The goals should take into consideration the effect of diminishing returns.

The energy team should at least consist of representatives from each major facility, engineering, operations, and the union or labor representative. Other members might include personnel from purchasing, accounting, and finance. The team should have authority adequate to investigate prevailing energy supply and demand situations and to implement policy recommendations. Their tasks should be assigned a priority consistent with the current or potential importance of energy problems in the company operation. They should utilize those talents within the firm in making the analysis and implementing the programs.

2.3 Surveying energy uses and losses

The first step for the energy team is to use an energy audit to determine the amount of energy that enters and leaves a plant. This determination will probably be an approximation at first, but the accuracy should improve with experience. The audit consists of a survey and appraisal of energy and utility systems at various levels of detail.

There is a direct relationship between the extent of data collection and consolidation, and the subsequent evaluation of energy conservation opportunities. While an insufficient database may prevent the identification of several energy-saving opportunities, too extensive a baseline survey may prove unnecessary and wasteful by diverting funds and time from more rewarding conservation opportunities. While the best results can be obtained by conducting a thorough, comprehensive survey and analyzing all site energy and utility systems, time and budgetary constraints may impose limitations on the extent of survey and appraisal for various site energy systems.

Certain items should be covered. Power bills should be reviewed considering the quantities noted in 2.3.1. At least a “walk through” audit should be conducted and preferably a detailed audit. An audit will uncover such items as unnecessary operation of equipment, unnecessary high levels of lighting, no one assigned to turn off unnecessary lights and equipment, improper thermostat setting, unnecessary or excess ventilation, and obvious waste. A comprehensive tour will also involve acquisition of nameplate data, motor and lighting loads, and other system details.

2.3.1 Establishing the energy relationship and the power bill

It is important, from several standpoints, to establish the existing pattern of electrical usage and to identify those areas where energy consumption could be reduced. A history on a month-by-month basis of electric usage is available from the electric bills, and this usage should be carefully recorded in a format (possibly graphic) that will facilitate future reference, evaluation, and analysis.

The following list of items (where appropriate) should be recorded in the electric usage history:

- Billing month
- Reading date
- Days in billing cycle
- Kilowatthours (or kilovoltampere hours if billed on this basis)
- Billing kilowatt demand (or kilovoltampere demand if billed on this basis)
- Actual kilowatt demand (or kilovoltampere demand if billed on this basis)
- Kilovar demand (actual and billed)
- Kilovar hours (actual and billed)
- Power factor
- Power bill (broken down into the above categories plus fuel cost)
- Production level
- Occupancy level
- Heating or cooling degree days
- Additional column(s) for remarks (such as vacation or high vacancy periods)

2.3.2 Project lists

This method utilizes a list of specific projects to reduce energy and costs. The engineer chooses a project from the list without study and evaluation. The project is implemented without an auditing of the electrical system to uncover and categorize areas of needed improvement. Shopping lists of projects are obtained from associates, newspapers, U.S. Department of Energy (DOE) magazines, the local utility, or trade groups. Local utilities often have demand-side management programs that offer financial incentives if certain conservation measures are pursued. These lists include readjustment of thermostats for heating, cooling and hot water; removing lamps in lighting fixtures; installing storm windows and doors; caulking; additional insulation; etc. An excellent reference is a do-it-yourself guide called *Identifying Retrofit Projects for Buildings* (Report 116)¹⁸ by the Federal Energy Management Program (FEMP) [B4].¹⁹

Nationally oriented standards can be helpful. Some have been issued by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. (ASHRAE) as part of ASHRAE/IEEE 90A-1-1988 [B1]. Other information sources include the Illuminating Engineering Society of North America (IESNA) documents, Building Energy Performance Standards (BEPS) by the National Institute of Standards and Technology (NIST), and *Total Energy Management* [B8], developed jointly by the National Electrical Contractors Association and National Electrical Manufacturers Association in cooperation with the DOE. Energy codes that specify permissible usage levels on various bases such as watts per square foot, or allowable illuminance levels, have been published by a number of states. Such information is likely to be available from a state energy office.

2.3.3 The energy audit

The amount of attention given will depend on the type of audit. A walk-through audit will require only a general notation of the performance, while a comprehensive audit will require specific information.

A comprehensive audit requires the development of a complete energy audit listing major energy-using equipment with nameplate data relating to energy, any efficiency tests, and estimates or measured hours of operation per month. This will include monthly utility data, amounts, and total costs. National Weather Service monthly degree days for heating and cooling must be included. Generally, a one- or two-year compilation of data is used. The crucial part is an intelligent appraisal of energy usage, what is done with energy as it flows through the processes and facility, and how this compares with accepted known standards. This study can lead to the development of a prioritized list of projects with a high rate of return.

A walk-through audit consists of a careful observation of operations while walking through the facility with the express purpose of uncovering energy conservation opportunities (ECOs). These ECOs are noted on a clipboard or other means during the tour of the facility. Six categories for energy use should be analyzed as the tour is conducted. These six categories are as follows:

- a) Lighting: interior, exterior, natural, and artificial
- b) The heating, ventilating, and air conditioning (HVAC) system and the heating and cooling effects of conduction, convection, and radiation
- c) Motors and drives
- d) Processes
- e) Other electrical equipment (transformers, contactors, conductors, switchgear, etc.)
- f) Building shell (thermal infiltration, insulation, and transmission)

Within each of these categories, the four basic energy saving methods (see 2.1.2) shall be considered.

¹⁸This publication is available from the U.S. Department of Commerce, Technology Administration, National Technical Information Service (NTIS), Springfield, VA 22161.

¹⁹The numbers in brackets correspond to those of the bibliography in 2.9.

2.3.4 Establishing load type for demand control

Chapter 4 covers the topic of demand control in detail. However, this subject is discussed now, because the foundation of demand control is the identification of those loads that can be controlled. The second part, of course, is controlling those loads to reduce demand. An important part of the audit process is, therefore, the identification of the curtailability of each process or piece of equipment. Each piece of equipment or process shall be identified by at least the following four “control” categories:

- a) *Critical*. Critical equipment/processes are those whose energy curtailment will be detrimental to the operation of the facility. Equipment that is required for safety reasons and/or for “high worth” to the facility is in this category and must be left energized. These loads shall not be made a part of a demand control scheme nor be turned off indiscriminately.
- b) *Necessary*. Necessary equipment/processes are those whose continual energization is important to the operation of the facility. However, these items can be deenergized at some specific loss to the facility. (Safety systems are never categorized as “Necessary.” They are always categorized as “Critical.”) Economic models can be developed to determine the benefit versus loss upon deenergizing “Necessary” loads. Disconnecting this equipment must not violate health, safety, or environmental needs of the facility and its operation.
- c) *Deferrable*. Deferrable load is that equipment/process that can be deenergized for a given period of time without any financial, production, or other loss. However, caution shall be taken to ensure that the equipment/process 1) can be safely disconnected and reconnected, 2) can withstand the frequency and duration of the anticipated starts and stops, and 3) does not indirectly involve the health environment or safety and/or production level of the facility.
- d) *Unnecessary*. This equipment should not be in operation; so, it shall be shut off as soon as possible. In addition, means should be installed to ensure that this load is deenergized when not required.

2.4 The six equipment audit categories

The ensuing subclauses propose questions that direct attention to possible energy savings. This is not a comprehensive list, but it will be helpful in elevating an awareness of energy waste and conservation opportunities.

2.4.1 Lighting

The first item that gets attention is lighting because of its visibility. Before making changes, read Chapter 7 Key efforts in analyzing and considering lighting from a conservation standpoint are noted below. It is wise to make checks both day and night.

- Is the light intensity sufficient for the task? [15–40 fc (160–450 lx) for halls; 70–100 fc (750–1100 lx) for detailed work.]
- Is the luminaire proper for directing the light where it is needed?
- Is the reflection good?
- Is the color right for the task?
- Is the luminaire too high or too low?
- Can task lighting be used effectively?
- Is good use being made of available natural light?
- Can desks or machines be grouped by task light required?
- Are lights and luminaires cleaned periodically?
- Are lamps turned off when not in use?
- How many luminaires can be turned off by a single switch?
- Who turns the lights off?
- Who uses the space and how often?
- Can a different, lower wattage lamp be used in the fixture?
- Do the surfaces reflect or absorb light?
- Are the luminaires strategically located?

- Does the luminaire location cause glare?
- Can lighting be used to heat?
- Can more efficient light sources be used?
- Can timers or photocells be effectively used?

2.4.2 Heating, ventilating, and air conditioning (HVAC)

Key factors in evaluating and better utilizing the HVAC system are as follows:

- a) Are there obstructions in the ventilating system?
 - 1) Do filters, radiator fins, or coils need cleaning?
 - 2) Are ducts, dampers, or passages and screens clogged?
- b) Is the wrong amount of air being supplied at various times?
 - 1) Are dampers stuck?
 - 2) Is exhaust or intake volume too high or too low?
 - 3) Are all dampers functioning in the most efficient manner?
- c) Can the system exhaust only the area needing ventilation?
- d) Can the system intake only the amount required?
- e) Can air be recycled rather than exhausted?
- f) Can the intake or exhaust be closed when the facility is unoccupied?
- g) Can the system be turned off at night?
- h) Is the temperature right for the area's use? [A 40–50 °F temperature may be acceptable for storage.]
- i) Can temperature setback be used effectively?
- j) Will an adjustable speed drive be more efficient?
- k) How many fixtures can be turned off by a single switch?
- l) Is solar energy being effectively utilized?
 - 1) Light, but minimum heat in summer
 - 2) Light and heat in winter
- m) Can waste heat be used?
- n) Are belts properly tensioned?
- o) Are pulleys and drives properly maintained and lubricated?
- p) Is the refrigerant proper?
- q) Can heat be redirected?
- r) Is the proper system being used?
- s) Is there too much or too little ventilation?
- t) Can the natural environment be used more effectively?
- u) Are doors, windows, or other openings letting out valuable heat?
- v) Can weather-strip, caulking, or other leaks be repaired?
- w) Can additional insulation be justified?
- x) Can all hooded exhaust systems have their own air supply or can they be used as part of the exhaust requirement for the building?
- y) Is the blower cycled or run continuously?

2.4.3 Motors and drives

Since motors use nearly 70% of the electrical energy consumed in the U.S., they provide great opportunity for reducing energy waste. The following questions point to very common kinds of waste:

- a) Does the motor match the load?
- b) Can the motor be stopped and then restarted rather than idled?
- c) Is the motorized process needed at all? Can it be done manually?
- d) Who lubricates the motor and associated drives? Is this done at the proper intervals?
- e) Can motor heat be recycled?
- f) What type of drive is used? Is it the most efficient?

- g) What is the voltage and is it balanced?
- h) Can the motor be cleaned to lower heat buildup?
- i) How is load adjusted?
- j) Will two (or more) motors in tandem work better?
- k) Is the motor well maintained and in good condition? Are there any electrical leaks to ground? Is the motor in a wet environment?
- l) Who turns the motor off and on? How often?
- m) How efficient is the motor?

2.4.4 Processes

Normally, processes rely heavily on motors, but there are other electrical parts. Process heating is probably the most common non-motor electric process load. The following questions point to areas where improved efficiencies can be made:

- a) Can equipment or processes be grouped together to eliminate the transportation of the equipment or material in process?
- b) Is the temperature too high?
- c) Does heat escape? Can insulation be used effectively?
- d) Can the heated energy be recirculated for comfort, process heat, or cogeneration? Can it be exhausted for summer comfort?
- e) Is preheat required?
- f) Can the process be staged or interlocked?
- g) Is the product heated, cooled, and then reheated again? If so, a continuous process may be appropriate.
- h) Can the processes be lined up for more effective use of equipment?
- i) Are the drives, beatings, etc. correctly lubricated?
- j) Can the conveyer system be eliminated or modified?
- k) Can hot areas be isolated from cold areas?
- l) Is one large motor or many small motors better?
- m) What equipment can be switched off at night?
- n) Would two or three shifts be more efficient?
- o) Is any equipment kept idling rather than switched off when in hold or waiting?
- p) Are screens cleaned and dampers checked for proper operation of pollution controls, and are they maintained at proper intervals, etc.?
- q) Is compressed air made in two or three stages? Is a storage tank being used and is pressure too high?
- r) Is process water too hot?
- s) Can fluid be recirculated?
- t) Is the fluid cooled too much?
- u) Is the hot water heater close to where the hot water is needed?
- v) Is the process exhaust higher than required for safety or quality, or both?
- w) Is hot and cold piping insulated where appropriate?
- x) Is temperature controlled so that only necessary heat is added?
- y) Is heat supplied or added at the point of use or is it transmitted some distance?

2.4.5 Other electrical equipment

There is a significant amount of electrical equipment that is taken for granted or rarely noticed. The list below contains some key questions regarding efficiency.

- a) Are the transformers required?
- b) Is the transformer too hot?
- c) Can the transformer be turned off when not in use?
- d) Are wiring connections tight? (Improper voltage, unbalanced voltage, and excess heat can result from a bad connection.)

- e) Can heat from the switchgear room be utilized? (Remove this heat during the summer.)
- f) Are voltage taps in the proper position?
- g) Are heaters applied properly?
- h) Can heaters be switched off at times?
- i) Are contactors in good working order?
- j) Is equipment properly bonded and grounded?
- k) Are conductors sized properly for the load?
- l) Is the power factor too low?

2.4.6 Building environmental shell

The list below is applicable to electrically heated buildings and also where other energy sources are used.

- a) Is allowance made for transition from cold to hot areas and vice versa with an air curtain or vestibule?
- b) Can a wind screen keep air infiltration down?
- c) Is the proper level of insulation applied?
- d) Can full advantage of solar heat be taken? (Remove solar heating effect in summer.)
- e) Is automatic door closing appropriate?
- f) Can covered loading and unloading areas be utilized to keep heat in?
- g) It is possible to caulk, weather-strip, glaze, or close-off windows?
- h) Can double- or triple-pane glass be used?
- i) Is a small positive pressure used to keep out drafts?
- j) Can areas be staged in progressively cooler or warmer requirements?
- k) Would an air screen, radiant heater, etc. be more effective?
- l) Are dock seals used on overhead doors?

2.4.7 Overall considerations

All conservation changes shall be made while considering the overall plant. An electrically heated building will use the heat from lighting fixtures in the winter, so reduced lighting may just transfer the heat requirement to baseboard heaters. While this chapter provides many areas for improved efficiency, a detailed analysis and engineering design by a competent consultant will be required. The final design shall include the consideration of proper codes (National Electrical Code®, Occupational Safety and Health Administration Codes, National Fire Protection Association Codes, and Environmental Protection Agency Codes, etc.).

2.4.8 Energy balance

An important step in evaluating opportunities is the development and analysis of major energy balances. An energy balance is a little more complicated than an energy survey and is based on measurement and calculation.

A basic energy balance is shown in figure 2-1. Energy is input to a system that produces a product. There is a certain amount of energy absorbed in the process, which can be called energy output. The difference between the energy input and the energy output is waste. Energy balances should be developed on each process to define, in detail, energy input, raw materials, utilities, energy consumed in waste disposal, energy credit for by-products, net energy charges to the product, and energy dissipated or wasted.

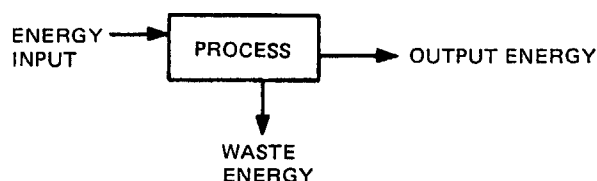


Figure 2-1 —Energy balance

All process energy balances should be analyzed in depth. Various questions should be asked and answered, including:

- a) Can waste heat be recovered to generate steam or to heat water or a raw material?
- b) Can a process step be eliminated or modified in some way to reduce energy use?
- c) Can an alternate raw material with lower process energy requirements be used?
- d) Is there a way to improve yield?
- e) Is there justification for replacing old equipment with new equipment requiring less energy or replacing an obsolete, inefficient process with a new and different process using less energy?

The energy survey and energy balances identify energy wasting situations and differentiate between those that can be corrected by maintenance and operations actions and those that require capital expenditures. The former can be corrected in a short time and the results are almost immediate—savings with little effort or delay. The latter will require some investment dollars and delivery time for materials and equipment.

The survey can be conducted by an individual, a team, or an outside consultant. The work can be segregated according to plant areas or departments. However, those conducting the survey shall be aware of the importance of finding waste, determining the cost involved, and reducing the energy costs. The initial survey shall be followed up periodically with additional surveys to ensure that waste is curbed and new problems are avoided.

2.5 Energy conservation opportunities

A key element of the energy management process is the identification and analysis of energy conservation opportunities (ECOs). These opportunities involve the previously listed spectrum of activities, from simply changing procedures or switching off lights to new long-range technologies.

The equipment used in operating a facility or in manufacturing a product plays another key role in the energy conservation effort. By understanding the relative energy consumption by equipment type, one can determine the opportunities that exist for decreasing this consumption.

After developing the energy balance and listing all of the energy conservation projects, each project should be evaluated for implementation using the following procedure:

- a) Calculate annual energy savings for each project.
- b) Project future energy costs and calculate annual dollar savings.
- c) Estimate the cost of the project, including both capital and expense items.
- d) Evaluate investment merit of projects using measures such as return on investment, etc.
- e) Assign priorities to projects.
- f) Select conservation projects for implementation and request authorization to proceed.
- g) Implement authorized projects. Examples of electrical energy conservation opportunities are described in 2.4. Application of a specific ECO requires careful evaluation to determine if its use is appropriate because there is the possibility that an ECO could be counterproductive. For instance, the proposed change may cause existing equipment to exceed operating limits.

2.6 Energy monitoring and forecasting

Managing energy is more than the implementation of energy conservation opportunities. Since energy management is a continuous process, it is extremely important to monitor energy usage and to use the results to gauge future actions. In some energy applications, such as in combustion processes, measurement or control (or both) at each point of application may be necessary to ensure efficient use of energy. Measuring methods that best describe the process are thus necessary to control, evaluate, and manage efforts to conserve energy. It is also important to budget the anticipated energy usage so that performance can be evaluated and plans can be made. A measure against budget also provides input to determine if additional action is required.

Several types of reports can be prepared to show energy usage over time. Summary reports for upper management typically note monthly or quarterly performance by facility or division. The type of report will vary with each specific facility. Some typical reports are the percent energy reduction method, the product energy-rate method, and the activity method. These reports are detailed in 2.6.1. Quick response to energy wastes and evaluation of the energy efficiency of a facility is better gauged using energy forecasts and tracking. This type of activity is described in 2.6.2.

2.6.1 Energy management reports

A number of very useful methods to maintain energy conservation performance in plants and offices worldwide are described in [B2]. Other established effective methods are given in [B5], [B6], [B7], and [B8]. In engineering new facilities, potential conservation is monitored using either the percent reduction energy-rate method or the design energy-savings report. For existing facilities, [B2] states that energy conservation is monitored using the activity method, the energy-rate method, the variable energy-rate method, or tracking charts.

2.6.1.1 Percent reduction energy rate method

This reduction is determined by comparing the project's product energy rate, expressed in Btu/lb (kJ/kg) with the existing plant's product energy rate. An example is shown in table 2-1.

The product energy requirements consist of all energy supplied minus credit for all usable energy exported. The requirements include purchased energy such as gas, oil, and electricity, plus generated in-plant utilities such as steam, refrigeration, compressed air, and cooling water. All energy, purchased or generated, has to be expressed in the same units (e.g., Btu). Likewise, the manufacturing department is given x credit for usable energy that is exported such as condensate and steam.

Table 2-1 —Product energy rate

Current production rate	= 1950 Btu/lb
Projected production rate	= 1480 Btu/lb
Percent reduction in product energy rate = $\frac{1950 - 1480}{1950} \times 100 = 24\%$	

2.6.1.2 Design energy-savings report

The design energy-savings report covers an energy-savings idea that is incorporated in the design of a project. The report serves three purposes:

- It is a means of information exchange on energy-saving ideas.
- It provides an opportunity to monitor energy conservation capital requirements versus energy savings on projects.
- It assists in an energy-awareness program in the engineering department.

This report is prepared by a project participant when that participant incorporates an energysaving idea or innovation that will reduce energy requirements. The guideline for an energysaving idea is that it deviates from present design or plant practices for the product line. If it is a new product, the reference point is the pilot plant or project definition report.

A summary report is issued quarterly on the number of energy-saving ideas submitted by each design group. This quarterly report encourages competition between design groups.

2.6.1.3 Activity method

The activity method compares the anticipated energy saved with energy purchased. The percent energy savings is based on the annual energy savings, expressed in Btu, compared with the plant's total purchased energy.

The activity method gives a rapid response to conservation results. Equally important, savings are not affected by changes in product energy efficiency as the production rate varies. For these reasons, it is an excellent method for monitoring performance.

A typical quarterly report for a company using the activity method is that shown in table 2-2. A similar report can also be prepared expressing the savings in Btu and costs; these statistics are most useful for internal communications and external publicity.

Table 2-2 —Activity method report

XYZ Manufacturing Co. Energy-conservation results Activity method (% energy savings)					
Plant	3 Quarters	4th Quarter	Year 0 Total	Planned activities	
				Year 1	Year 2
Fulton	2.0	0.2	2.2	2.1	1.0
Grace	1.8	0.1	1.9	0.8	0.4
Nixon	1.5	0.2	1.7	2.3	0.3
St. James	0.8	0.4	1.2	0.1	0
Company TOTAL	1.7	0.3	2.0	1.8	0.4

The activity method yields a good visual report on activities that have been completed and planned to save energy. However, it does not reflect the true reduction in energy rate (Btu/lb of products) because the savings are annualized.

2.6.1.4 Energy-rate method

The Chemical Manufacturers Association (CMA) developed the chemical-industry energy-rate method for reporting energy conservation results. An example of the calculations is shown in table 2-3. The Year 0 base period rate is calculated using the total “pounds of product” manufactured in Year 0 and the equivalent purchased energy consumed by the department manufacturing the product. The equivalent energy includes energy consumed by the specific line plus a proportionate share of energy that cannot be assigned (or measured) to any one area.

For any reporting year, the percent reduction in energy consumption rate is calculated by comparing the base period energy to the total energy purchased by the plant, excluding feedstock energy. The comparison base period energy for

each product is calculated using the base year product energy rate times the weight of the product manufactured in the current year.

The CMA energy-rate method of reporting conservation results compensates for product mix, the addition and deletion of products, and for OSHA and environmental energy requirements. Changes in production rate have a major effect on conservation results because the product energy-rate requirements are made up of fixed and variable energies.

2.6.1.5 Variable energy-rate method

Many variables need to be considered in a conservation monitoring method, including the following:

- a) Changes in energy rate as production rate varies (see figures 2-2 and 2-3)
- b) Product energy requirement changes resulting from ambient temperature changes during the year
- c) Changes in raw material quality
- d) Changes in the plant heat balance that may cause the process to operate turbine drives instead of motor drives, and vice versa
- e) Minor changes in product quality or specifications for different customers
- f) A change in the equipment or process to increase output

The product energy-rate versus production-rate curve in figure 2-2 was developed for each product considering only production rate and its effect on the energy rate as variables. To calculate the conservation performance for any year, the product production rate for that year is used to establish the base period energy rate from the energy-rate curve of figure 2-4. For example, using the CMA energy-rate method for Year 0, the product energy rate is 10 000 Btu/lb. The actual base energy rate is 11 500 Btu/lb.

The 11 500 Btu/lb base energy rate instead of 10 000 is used in calculating the comparison base-period energy rate for product G. This same procedure is then duplicated for each product. This method, although not 100% accurate in compensating for all variables, does compensate for the major variable, production rate, and does prevent wide swings in conservation results as the production rate varies.

2.6.2 Energy management and forecasting methodology

Tracking of energy on a quarterly or annual basis does not afford the engineer with an opportunity to quickly react to energy problems. Also, it is important to utilize audit information to establish an energy budget. The use of a budget, and/or a projected usage allows evaluation of energy efforts and properly gauges the energy portion of the cost of doing business.

From a forecast viewpoint, energy usage shall be classified into two groups. *Baseline energy* is the energy component that is constant over the measurement period and does not vary with production, weather, etc. *Variable energy* is the component that changes with production, weather, occupancy, etc. These two components should be determined for the facility in order to properly gauge and monitor energy performance. Although this standard discusses electrical energy, it is recommended that the same technique be applied to other energy source inputs such as steam, chilled water, and direct combustion of other fuels.

Table 2-3 —Energy rate method report

Fulton plant Products manufactured	Year 0 (Base period)			Year 3			
	Total production (× 10 ⁶ lb)	Total energy (×10 ⁶ Btu)	Base energy rate (Btu/lb)	Total production (×10 ⁶ lb)	Total energy (×10 ⁶ Btu)	Comparison base period energy (×10 ⁶ Btu)	% Reduction energy consumption rate
	Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7
A	200	10 000	50	300		15 000	
B	10 000	30 000	3	12000		36 000	
C	2 000	20 000	10	3 000		30 000	
D	<u>3 000</u>	<u>60 000</u>	<u>20</u>	<u>6 000</u>		<u>120 000</u>	
Adjustments to base:	15 200	120 000		21 300		201 000	
New products (+) or							
discontinued products (–)							
after Year 0 (base).							
E (Year 1)....	1 000	10 000	10	2 000		20 000	
F (Year 2)....	<u>1 000</u>	<u>5 000</u>	<u>5</u>	<u>1 000</u>		<u>5 000</u>	
	<u>2 000</u>	<u>15 000</u>		<u>3 000</u>		<u>25 000</u>	
Total products	17 200	135 000		24 300	208 000	226 000	7.5*
Adjustments for							
environmental and OSHA							
	<u>Base</u>			<u>—</u>	<u>(1000)</u>		
Adjusted grand total	17 200	135 000		24 300	207 000	226 000	8.0*
* % Reduction energy consumption rate = $\frac{(\text{Column 6}) - (\text{Column 5})}{(\text{Column 6})} \times 100 = (\text{Column 7})$							

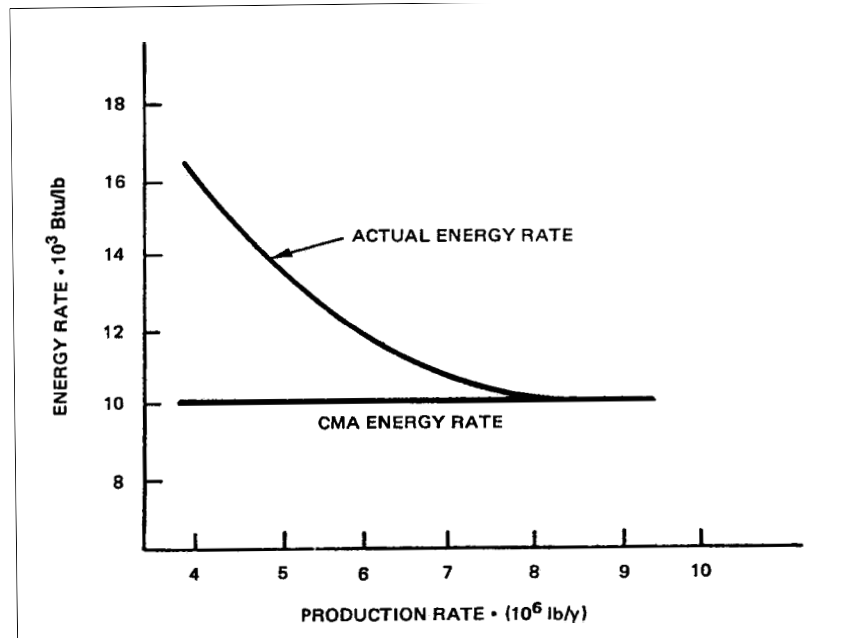


Figure 2-2 —Change in production

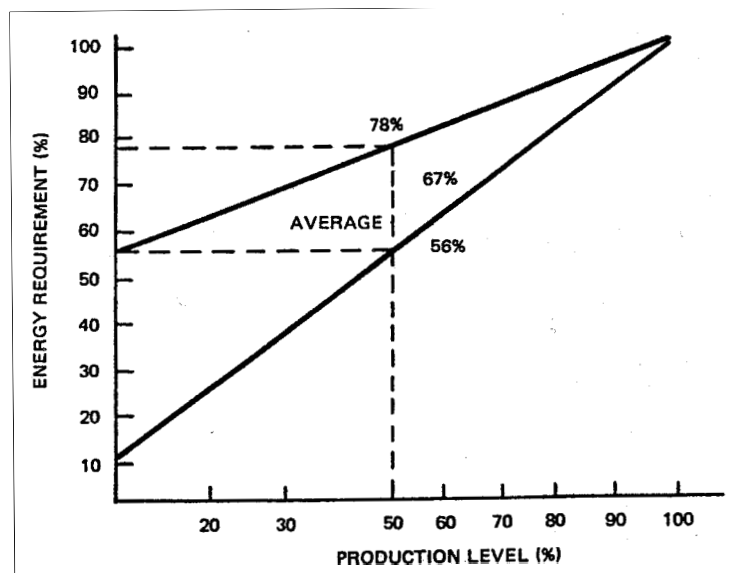


Figure 2-3 —Energy versus production

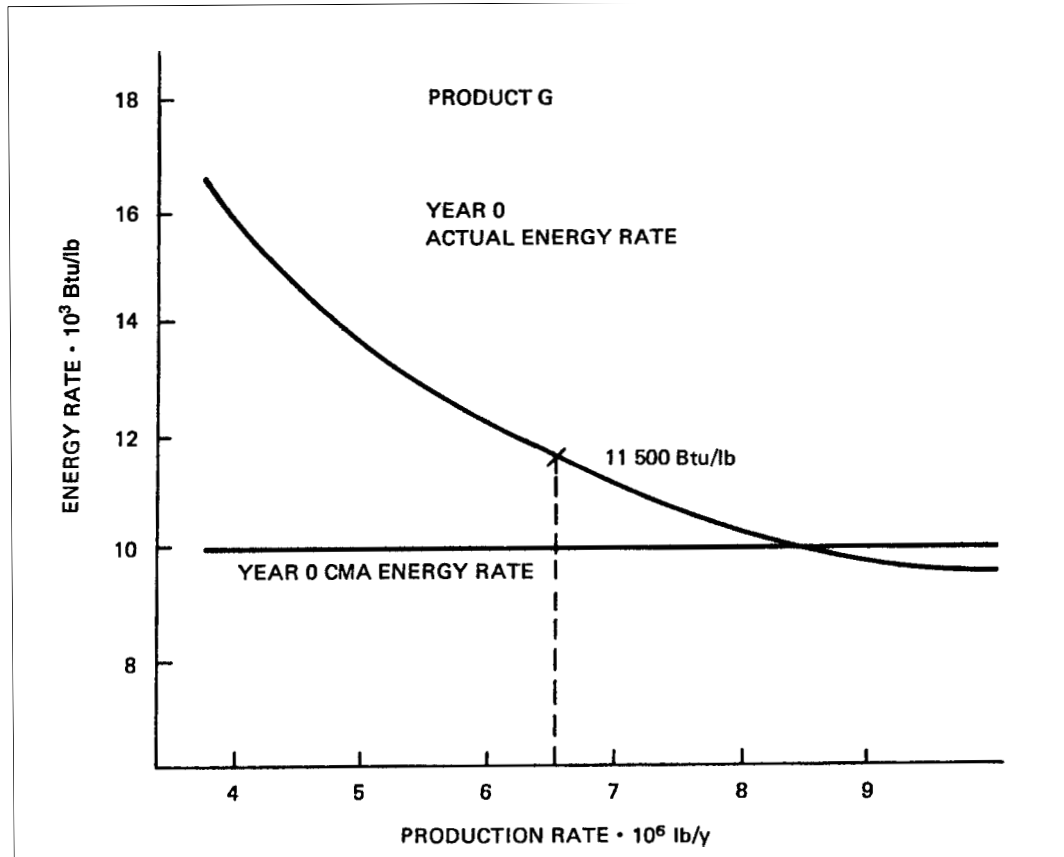


Figure 2-4 —Actual and CMA energy rate versus production rate

This subclause will review an industrial situation to guide the reader through the energy monitoring and budgeting process. The same concept can be applied to commercial buildings by replacing “product” with “occupancy,” “weather,” etc.

The first step in energy budgeting is the performance of a usage audit. It is preferable to review results of the previous 12 months (see 2.3, 2.4, and all of Chapter Chapter 8 for metering and auditing information). Both usage and production should be reviewed. With properly installed meters whose readings were diligently tabulated, results are very easy to obtain. The engineer can use these results in working with production personnel to obtain their forecast of production and the associated projected energy use.

Installation of meters as shown in figure 2-5 allows for the calculation of process efficiency for various input and consumption variables.

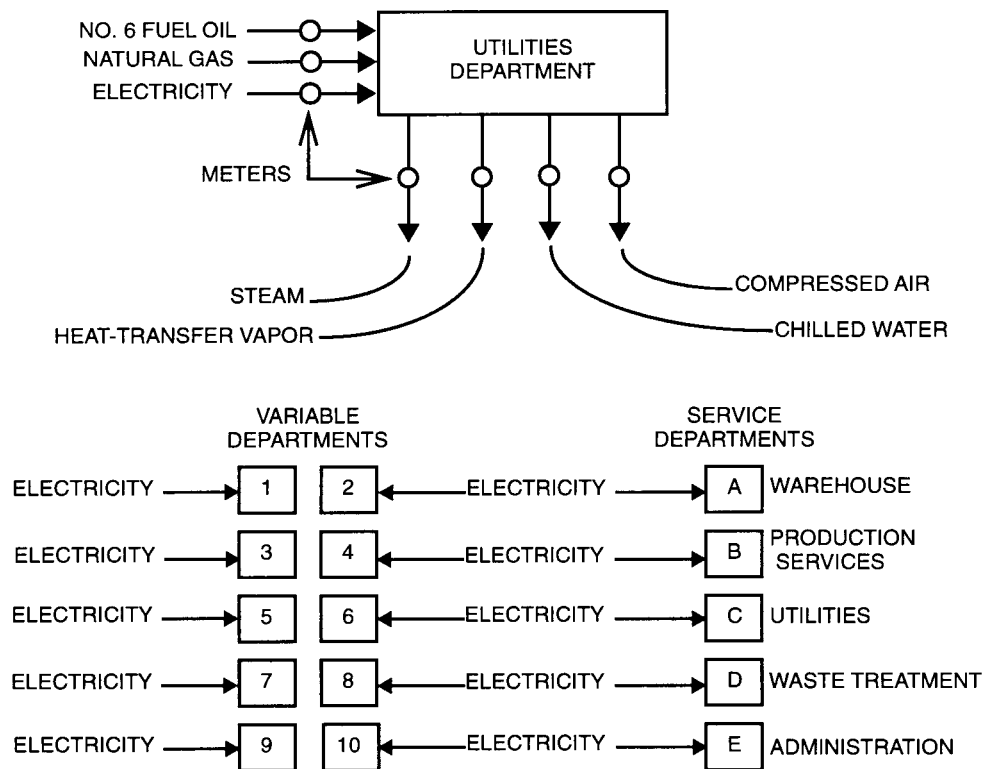


Figure 2-5 —Typical plant energy distribution

This subclause will discuss the electric portion only. The production estimate is received from the production people in several forms (e.g., figure 2-6). The anticipated monthly production run can be used in total and then an average daily figure can be calculated using average kWh/lb of daily product. The forecast can also be calculated by using the anticipated hours of machine use for the month and/or day. The calculation can be done on a form similar to that shown in figure 2-6. The resulting information, as well as the base values, can be put on a summary form, an example of which is shown in figure 2-7. Both the estimate and the actual numbers can be conveniently noted. If available, both the production estimate and usage estimate on machines should be used to determine the variable portion of the electrical usage. The results from using the two estimates should converge as time hours progresses, unless one or the other is not a good gauge of kWh usage.

Total actual electrical consumption is then plotted on a graph. Two types of graphs are shown in figures 2-8 and 2-9. Although these graphs are by months, it is important to keep an energy track for shorter periods—even in shifts—by department and/or activity. A review of the information frequently will reveal a more efficient way to produce a product or service. For example, energy information was tracked by pound of product produced for each shift in a cement plant. An analysis of the results over time showed that the most energy-efficient shift kept the machines running the entire shift rather than shutting down frequently to make changes in the production run. The remaining shift supervisors were asked to keep machines running and the resultant savings were over a quarter million dollars in energy costs. Figure 2-10 shows one way of reporting energy usage on a monthly basis.

_____ Production Forecast		
For		
Department _____ is _____ MGP		
I.	_____ ÷ _____ = _____	
	MGP Days in Month MGP/Day	
II.	_____ ÷ _____ = _____	
	MGP/Day MGP/ Average Machine-Day Machine Level	
III.	_____ × _____ = _____	
	Average Days in Month Machine-Days Machine Level In Month	

NOTE—MGP is thousands of gallons of product per minute.

Figure 2-6 —Production forecast form

A plot of production versus energy usage can be used to develop a formula for predicting energy usage. The regression analysis of “least squares” (software is available) or “eye balling” can be used to establish a formula that fits the data points. Figure 2-9 shows a “curve” that “fits” the data. The curve is a straight line with a slope of 1705 and an intercept at 139 500 kWh per month. The equation would be as follows:

$$1705 \times M + 139\,500 = \text{kWh per month}$$

where

M = thousands of pounds of net good product per day, where the plant produces product 24 hours per day for 31 days

This analysis shows that the baseline portion of the energy bill is 139 500 kWh per month. The baseline is essentially fixed, but that does not mean that an energy audit of the baseline portion is not a place to reduce electric energy usage. In this example, the baseline energy represents 31% of the energy usage at full production (180 000 lb of good product per day).

Energy Analysis for Department: _____ Machine type: _____

	Std	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year Avg
Machine days														
Thousands of net good pounds														
Thousands of kWh per machine day														
kWh per net good pounds														
MSCF air—Machine day														
SCF air—NGP														

NOTE—MSCF = Thousands of standard cubic feet; SCF = Standard cubic feet; NGP = Net good pound of product.

Figure 2-7 —Energy usage analysis form

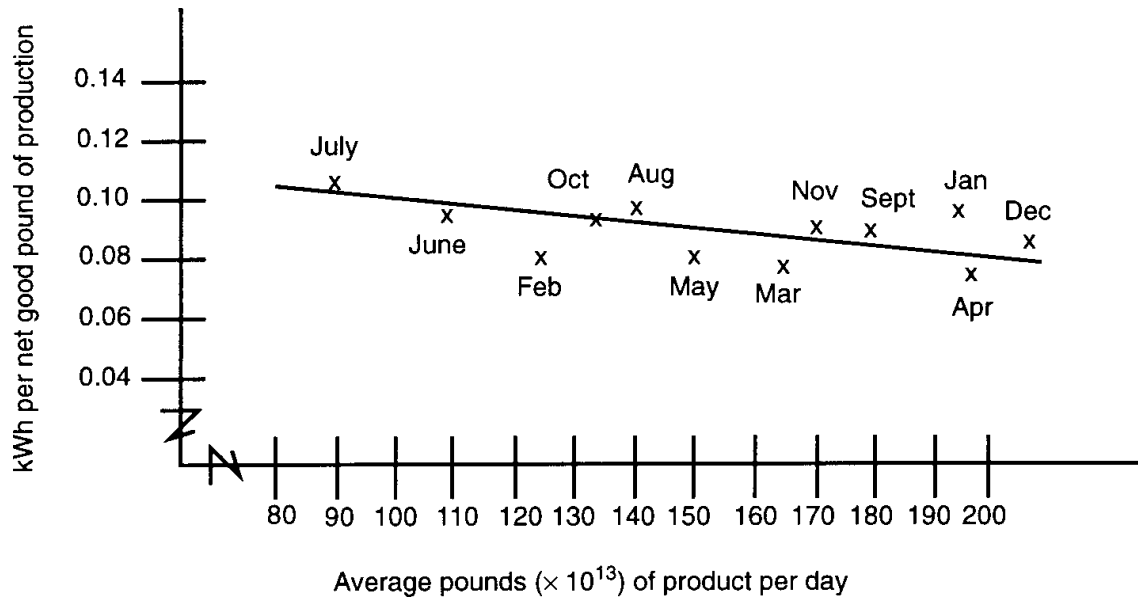


Figure 2-8 —Per unit kWh consumption

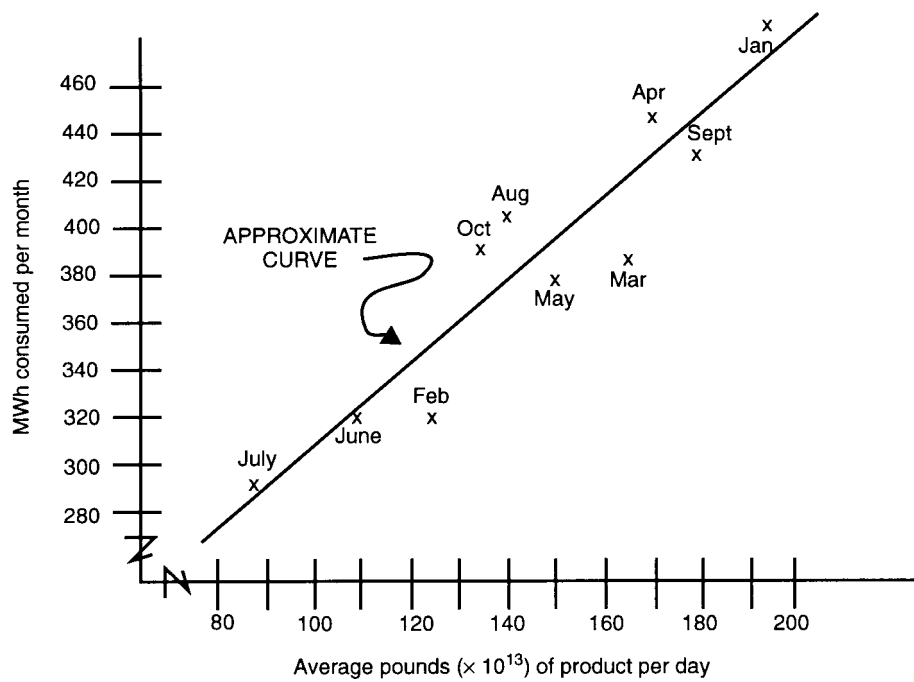


Figure 2-9 —Monthly MWh consumption

Variable and Service Energy Forecast Summary Sheet

		Month, Days		
Dept. no.	Machine electricity (kWh $\times 10^3$)	Air (SCF $\times 10^3$)	Steam (Btu $\times 10^6$)	Heat transfer vapor (Btu $\times 10^6$)
1				
2				
3A				
3B				
3C				
3D				
4				
5				
6				
7				
8				
9				
10				
Total variable				
Warehouse				
Utilities				
Waste treatment				
Production services				
Administration				
Construction				
Chillers				
Losses				
—Service air				
—Steam				
Total services				

Figure 2-10 —Variable and service energy forecast summary sheet

2.7 Employee participation

An energy conservation program can be successful only if it arouses and maintains the participative interest of the employees. Employees who participate and who feel themselves partners in the planning and implementation of the program will be more inclined to share pride in the results.

Communicating with employees on the subject of energy can be accomplished in many different ways: face to face discussion, seminars and workshops, distribution of informative and descriptive literature, slide presentations and moving pictures, and most important of all, sincere practice of conservation on the part of management at all times.

The use of company newsletters, bulletin boards, or posters for pictorializing energy conservation objectives and accomplishments will help impress employees with the importance of such matters. Employee participation can be increased by communicating examples of energy conservation ideas being implemented, photographs of persons who submitted the ideas, and information on the savings realized.

Competition between departments, sections, or groups within the company in pursuing conservation of energy can also generate enthusiasm among employees. Competitive programs can be initiated among the employees and should be encouraged. Acknowledgment of good ideas and positive reinforcement are keys to this approach. Employee education can take many diverse forms: workshops and training courses for supervisory personnel, articles in the company newsletter, and energy conservation checklists given to each employee.

A clear, concise list of firm do's and don't's to guide employees in performance of their work can be helpful in achieving energy conservation practices. Such lists should be distributed to all employees whose jobs involve the use or control of energy. The list should be updated as often as necessary. Supervisors should be responsible for seeking adherence to all items on the list.

2.8 Summary

Energy management is a broader concept than energy conservation. In energy management, one is attempting to achieve the same level of productivity with a lower expenditure of energy, an adequate energy supply, and the lowest possible cost.

Energy management responsibility requires a significant reorientation of managers toward energy conservation. Corporate individualism operating under the profit motive in a free marketplace has been a major factor contributing to U.S. economic success. These achievements have also been due, in part, to the industrial manager's dedication to the substitution of inexpensive electric and thermal energy for human labor in the production of goods and services.

We now find that it is necessary for management to accept the reality that the future requires a major reorientation because energy input is no longer going to be inexpensive. To secure energy supplies and to minimize energy costs, industry will have to act in conjunction with its own members, government, the public, and all segments of the energy supply industry.

Achievement of meaningful energy savings in existing processes is a function of management committing itself to do the job by effective personnel motivation, planning, and administration. The establishment of a formalized energy management responsibility is highly desirable to give the effort both the focus and the direction required. An energy management function gives the line manager the tools to get the job done. Engineers should inform upper management regarding energy use and costs, future energy supply cost and availability, and the level of savings possible. The engineer can then convince management of the need for alternative solutions that should be pursued.

Obtaining participation from key local plant operators is a prime ingredient to energy conservation success since they know their electrical system and generally are in the best position to take corrective action. However, top management must give them the monetary and technical resources required.

2.9 Bibliography

Additional information may be found in the following sources:

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[B2] Doerr, R. E., "Six Ways to Keep Score on Energy Savings," *The Oil and Gas Journal*, pp. 130–145, May 17, 1976.

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Chapter 3

Translating energy into cost

3.1 Introduction

The use of economic analysis is critical to the conservation program because monetary savings can significantly influence management decisions. The engineer shall, therefore, be able to translate a proposal into monetary value, i.e., expenditures versus savings. This chapter covers basic economic concepts and utility rate structures, and then addresses the subject of loss evaluation.

The engineer can use the economic basics to develop an energy program and to determine the best choice among alternatives. This determination should include understanding payback periods, understanding the time value of money, and weighing other pertinent costs.

An understanding of electric rate structures is essential in an economic analysis because the monetary savings will accrue from lower electric bills. Rate structures are sufficiently complex to warrant careful consideration. The electric rate is particularly important in demand control (load management) projects.

All electrical equipment has losses. The savings from loss reduction is calculated by evaluating the reduced cost of energy over the life of the equipment.

3.2 Important concepts in an economic analysis

Two or more alternatives are considered in an economic analysis (one may be to do nothing). In any case, an investment is usually evaluated over a period of time. The initial investment is called the capital cost. Since an item is usually worth less as it ages, the value is depreciated over its life. A piece of equipment normally has a salvage value (which could be negative if its removal or disposal cost is higher than its resale value) when it is retired and sold. In addition to the initial investment, an alternative usually has recurring costs such as maintenance and energy usage. These costs are grouped as annual costs and are then put in a form that can be added directly to the capital cost.

The capital cost represents the total expenditure for a physical plant or facility. The capital cost is comprised of two components: direct costs and indirect costs. Direct costs are monetary expenditures that can be directly assigned to the project such as material, labor for design and construction, and start-up costs. Indirect costs or overheads are expenditures that cannot be directly assigned to a project (e.g., taxes, rent, employee benefits, management, corporate offices, etc.).

Depreciation is the distribution of a capital cost over the anticipated life of the process or equipment. These depreciation amounts are then used to reduce the value of the capital investment. There are several means of distributing these costs; the simplest method is straight-line depreciation. In straight-line depreciation, the annual depreciation is merely the capital cost divided by the estimated life.

Equipment, material, and buildings have two values used for life expectancy: the book life and the expected or useful life. The book life is the number of years used to financially depreciate the investment. The expected life is the anticipated length of time that the investment will be utilized. Computers tend to become obsolete in only a few years due to rapid advances in technology today. However, computers can, and do, continue to compute long after their technological obsolescence; so the expected life in the case of a computer could be the time until obsolescence.

The salvage value is the amount of money that can be returned to the company at the end of the expected life of the capital investment. This salvage value is equal to the anticipated resale value minus any cost associated with 1) the sale of the equipment and 2) its physical disassembly and subsequent removal.

The annual costs include such items as fuel or energy, operation/maintenance, labor, taxes, and other recurring costs. The fuel cost depends on the amount, quality, rate of use, and the rate schedule. The maintenance cost includes both routine work and purchase of parts, such as the periodic relining of boilers.

3.3 Economic models—their applications and limitations

There are two general means of evaluating energy options: simple break-even analysis and a more complex method called life cycle costing. When there is a large energy savings for a small investment, simple payback may be the best evaluating tool. Furthermore, housekeeping projects with minimal or no cost may not need evaluating at all. For example, the installation of a timer on an exterior light circuit that will significantly reduce “on” time or a decision to switch off unused equipment may not need an economic evaluation. However, the subsequent effect of these actions should be shown to encourage management and support the energy conservation effort. Life cycle costing is most likely needed when the project costs are large compared to the energy savings or when there are significant future costs. The ensuing subclauses detail the various modeling methods.

3.3.1 Break-even analysis

The break-even methods do not use the time value of money, and they all answer the same question: At what point will I get my money back? Common terms for this model are simple payback analysis, break-even point analysis, and minimum payback analysis. All of these methods are essentially the same. They all relate the capital investment to the savings. Some methods chart results while others use a not-to-exceed value. The basic mathematical description is

$$\text{Break-even point} = \frac{\text{net capital investment}}{\text{savings/unit}}$$

Many companies have minimum payback requirements to allow expenditures whose break-even point is less than a given amount of time (or other measurement). The break-even point has taken the name of payback from this minimum payback usage. Hence, the more common term is payback, and management is more likely to ask for the payback of a particular energy option.

It is important to note that break-even analysis is not restricted to time as a base. Production and energy consumption are also good bases. For example, the break-even point can be calculated in terms of the amount of product manufactured such as dollar savings per pound of output.

When questions concerning future operations are appropriate, a more sophisticated method of analysis is justified, particularly if the minimum payback period exceeds several years. A complete, long-term analysis is well worth considering in determining energy savings.

3.3.2 Marginal cost analysis

Marginal (or incremental) cost analysis is more a concept than an economic model. The marginal concept has predominant use in the economic community and has popular use in making decisions. It is primarily used in calculating cogeneration sales to the utility and in the development of special rates or contracts. Marginal cost analysis is simply the determination and use of the next increment of the cost of money or cost of electric energy. It is usually prudent to consider costs of the next increment of power, production, investment, and money.

3.3.3 Life cycle costing

Life cycle costing (LCC) is the evaluation of a proposal over a reasonable time period considering all pertinent costs and the time value of money. The evaluation can take the form of present value analysis, which this subclause will use, or uniform annual cost analysis.

The LCC method takes all costs and investments at their appropriate points in time and converts them to current costs. Inflation is assumed equal for all cost factors unless it is known to differ among cost items. Items for consideration include the following:

- a) Design cost
- b) Initial investment
- c) Overheads
- d) Annual maintenance costs
- e) Annual operating costs
- f) Recurring costs
- g) Energy costs
- h) Salvage values
- i) Economic life
- j) Tax credits
- k) Inflation
- l) Cost of money

3.4 Time value of money

3.4.1 Determining the cost of money

A dollar today is worth more than a dollar in the future because today's dollar can generate profit. Most companies use the cost of borrowing and the return on investment to determine the cost of money. The energy engineer should work with the appropriate financial people to determine the cost of money.

Inflation, the rate of price increase, is a very important concept in the time value of money. For example, inflation may direct a decision to buy now or next year. If an item increases in cost by 20% a year and money can be borrowed at 10% a year, one should buy now. However, if the reverse is true, it might be wise to wait a year to purchase. In simplified economic evaluations, inflation is assumed to have equal effects on all alternatives; it should only be included in more complex analyses or if one or several items increase in cost at significantly different rates.

The time value of money is important to the engineer because the engineer shall be able to evaluate alternatives by translating a dollar of expense or investment at various times to equivalent amounts. To accomplish this task, the next subclause will develop conversion factors that translate future dollars or payments into their present values and vice versa.

3.4.2 Calculating the time value of money

The following list of terms is used in subsequent discussions:

annuity: A series of equal amounts evaluated at the end of equal time periods (usually 1 yr) for a specified number of periods.

capital investment: The amount of money invested in a project or piece of equipment (this includes labor, material, design, and debugging monies).

compound interest: Interest that is applied to both the accumulated principal and interest. For example, a 12% annual interest rate compounded at 1% each month on \$1.00 is $(1.01)^{12}$ or \$1.13, which results in a 12.7% effective (simple) annual interest rate.

constant dollars: The worth of a dollar amount in a reference year, including the effect of inflation. Constant dollars are used in economic indicators.

current dollars: The worth of a dollar today.

depreciation: The mathematical distribution of the capital investment over a given period of time, which may or may not concur with the estimated useful life of the item.

discount rate: The percentage rate used by a corporation that represents the time value of money for use in economic comparisons.

future worth (value): The value of a sum of money at a future time.

initial cost: Synonymous with capital investment. Capital investment is a more proper and clearly recognized term.

present worth (value): The value of an amount discounted to current dollars using the time value of money.

For the purpose of this subclause, it is assumed that the initial investments are made at the beginning of the first year, and the future expenditures are made at the end of the year. Hence, \$3.00 invested now at a 30% annual interest rate will grow to \$1.30 at the end of the first year (i.e., Year 1 in the formulas), and \$1.00 in operating and expense dollars for that year will have a \$0.91 present value (\$3.00/1.1 = \$0.93). The present worth is the value at Year 0 and the future worth is the value at the end of the n th year. The entire conversion process is based on two basic calculations: the present worth of a single amount and the present worth of an annuity.

The single present worth factor is used to find the present worth of a single future amount. The present worth factor (PWF) is determined by the following equation:

$$PWF = \frac{1}{(1 + i)^n}$$

where

i = Interest or discount rate expressed as a decimal
 n = Number of years

The present worth is calculated by multiplying the future amount by the present worth factor or

$$PW = PWF \times FW$$

where

PW = Present worth
PWF = Present worth factor
FW = Future worth or future amount

For example, suppose that a company has the choice of refurbishing an existing induction heating unit for \$10 000 (and replacing it in five years for \$120 000) or buying a new unit for \$100 000. The company's discount rate is 12%. The choice is whether to spend \$10 000 now and \$120 000 in five years or to spend \$300 000 now. To compare the alternatives, the \$120 000 future amount is converted to today's dollars.

Alternate A

Present: = \$10 000 PW

$$\begin{aligned} \text{Future:} &= \frac{1}{(1 + 0.12)^5} \times 120\,000 \\ &= \$68\,100 \text{ PW} \end{aligned}$$

Total: = \$78 000 present worth

Alternate B

Present: = \$100 000 PW

Future: = 0

Total: = \$100 000 present worth

In this case, there is a clear \$22 000 benefit in renovating the unit and paying a larger amount for a new machine in five years. Neglecting the time value of money would have led to the wrong decision.

The present worth of an annuity factor (PAF) converts a series of future uniform payments to a single present worth amount. The uniform payments are made at the conclusion of a series of equal time periods. The mathematical description of this factor is as follows:

$$\text{PAF} = \frac{(1+i)^n - 1}{i(1+i)^n}$$

= Present worth of an annuity factor

and

$$\text{PW} = \text{PAF} \times \text{AP}$$

where

AP = Annuity amount (or equivalent annual payment)

Suppose the induction heater in the previous example had an energy cost of \$20 000/yr but the new unit only cost \$15 000/yr to operate. The annuity factor will provide a base of comparison by including the annual energy cost as a single present worth amount. While the net cost or savings can be used, the actual amounts for each alternative should be used to reduce errors and clarify results.

Alternate A

Current expense: \$10 000 PW

Future capital investment: 68 100 PW

Future energy costs =

$$\frac{(1+0.12)^5 - 1}{0.12(1+0.12)^5} \cdot \$20\,000 = 72100 \text{ PW}$$

Total: \$150 190 PW

Alternate B

Current capital investment: \$100 000 PW

Future energy costs =

$$\frac{(1+0.12)^5 - 1}{0.12(1+0.12)^5} \cdot \$15\,000 = 54000 \text{ PW}$$

Total: \$154 000 PW

While the choice is still Alternate A, intangible factors could change the decision since the difference is only 2.7%.

The future worth factor (FWF) converts a single current dollar amount to a future amount. The future worth factor for a single present value is the reciprocal of the single present worth factor or

$$FWF = (1 + i)^n$$

$$FW = FWF \times PW$$

The future worth of an annuity factor (FAF) converts an annuity to a single future amount.

$$FAF = \frac{(1 + i)^n - 1}{i}$$

and

$$FW = FAF \times AP$$

The uniform annuity factor (UAF) is used to convert a single present amount to a series of equal annual payments. The uniform annuity factor is the reciprocal of the present worth of an annuity factor (PAF).

$$UAF = \frac{i(1 + i)^n}{(1 + i)^n - 1}$$

and

$$AP = UAF \times PW$$

It is frequently necessary to open a savings account for a future purchase, and the amount saved is called a sinking fund. The annuity (sinking fund) required to accumulate some future amount is determined by using the sinking fund annuity factor (SAF). The factor is simply the reciprocal of the future worth annuity factor (FAF) or

$$SAF = \frac{1}{(1 + i)^n - 1}$$

The preceding factors are summarized in table 3-1 and their use is graphically displayed in figure 3-1. However, most studies will use only the present worth of a single future amount and the present worth of an annuity factor. The next subclause describes the use of these factors in an economic analysis of energy options.

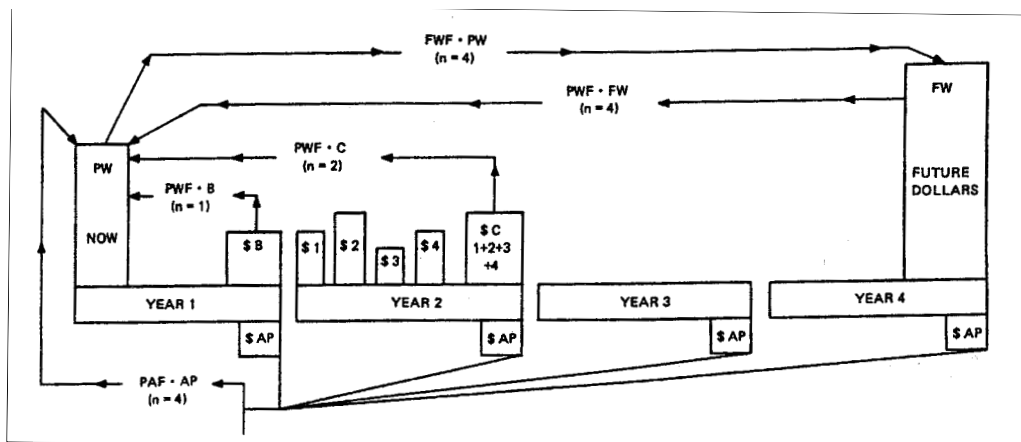
Table 3-1 —Time value factors

Symbol	Name	Description	Formula*
AP	Annuity payment	Equal amounts of money at the ends of a number of periods	—
FAF	Future worth annuity factor	Converts an annuity to an equivalent future amount	$FAF = \frac{(1+i)^n - 1}{i}$
FW	Future worth	The dollar amount (of an expense or investment) at a specific future time	—
FWF	Future worth factor	Converts a single present amount to an amount at a future point in time	$FWF = (1+i)^n$
PAF	Present worth annuity factor	Converts an annuity to a single present amount	$PAF = \frac{(1+i)^n - 1}{i(1+i)^n}$
PW	Present worth	The single value or worth today	—
PWF	Present worth factor	Converts a future amount to an amount today	$PWF = \frac{i}{(1+i)^n}$
SAF	Sinking fund annuity factor	Converts a future amount into an equivalent annuity	$SAF = \frac{i}{(1+i)^n - 1}$

*The two variables have the following definitions:

n = Number of years in the evaluation period

i = Interest rate or other cost of money factor used

**Figure 3-1 —Time value chart**

3.4.3 Life cycle cost example

The use of the time value of money formulas presented in 3.4 and summarized in table 3-1 is best illustrated by example. While the information presented in this example is representative of actual costs and equipment performance, it is intended only for illustration.

A 100 hp outdoor dip-proof (ODP) motor, which runs 5000 h/yr at an operating load of 75% of design, goes out of service. The plant engineer must choose one of the following:

- *Option 1.* Rewind the failed motor.
- *Option 2.* Purchase a new motor of normal operating efficiency.
- *Option 3.* Purchase a new motor of higher operating efficiency.

Option 1, motor rewind, costs \$1500 plus \$200 installation, and results in a motor operating efficiency of 90.9% for a first year energy operating cost of \$23 400, but will last for only 10 years. Option 2, purchasing a new normal-efficiency motor, costs \$2100 plus \$200 for installation, results in a motor operating efficiency of 91.9% for a first year energy operating cost of \$23 100, and will last for 15 years. Option 3, purchasing a new high-efficiency motor, costs \$2500 plus \$200 for installation, results in a motor operating efficiency of 94.8% for a first year energy operating cost of \$22 400, and will last for 15 years.

For the purpose of this illustration, it is assumed that there is a 30-year investment horizon and that each option is exclusive of the other. The rate of inflation is assumed to be 4%/yr and the corporate discount rate is set at 20%. The salvage value of each option at the end of the 30 years is assumed to be equal for all three options, and so is not considered in this illustration. Finally, the tax effects of the alternatives (such as depreciation) are not considered.

The life cycle costs of Option 1 consist of three motor rewindings (in Years 0, 10, and 20) and 30 years of operating costs. The life cycle costs of Option 2 consist of two normal-efficiency motor purchases (in Years 0 and 15) and 30 years of operating costs. The life cycle costs of Option 3 consist of two high-efficiency motor purchases (in Years 0 and 15) and 30 years of operating costs.

The present worth of the capital and installation costs of the future motor rewindings and future motor purchases are estimated using the future worth factors, FWF (to account for the effects of inflation), and the present worth factors, PWF (to discount these future expenses into present day amounts).

Present worth of capital and installation costs for Option 1:

1st rewind cost - \$1 500 + \$200 = \$1 700
 Future worth factor, 4% inflation, 10 years = $(1 + 0.04)^{10} = 1.480$
 Present worth factor, 20% discount rate, 10 years = $1/(1+0.20)^{10} = 0.162$
 2nd rewind cost = \$1 700 × FWF × PWF = \$406
 Future worth factor, 4% inflation, 20 years = $(1+0.04)^{20} = 2.191$
 Present worth factor, 20% discount rate, 20 years = $1/(1 + 0.20)^{20} = 0.026$
 3rd rewind cost = \$1 700 × FWF × PWF = \$97
 Present worth of 1 st, 2nd, and 3rd motor rewinds = \$1 700 + \$406 + \$97 = \$2 203

Present worth of capital and installation costs for Option 2:

The first normal-efficiency motor cost = \$2 100 + \$200 = \$2 300
 Future worth factor, 4% inflation, 15 years = $(1+0.04)^{15} = 1.801$
 Present worth factor, 20% discount rate, 15 years = $1/(1+0.20)^{15} = 0.065$
 2nd normal-efficiency motor cost = \$2 300 × FWF × PWF = \$269
 Present worth of 1st and 2nd motor costs = \$2 300 + \$269 = \$2 569

Present worth of capital and installation costs for Option 3:

1st normal-efficiency motor cost = \$2 500 + \$200 = \$2 700
 Future worth factor, 4% inflation, 15 years = $(1+0.04)^{15} = 1.801$
 Present worth factor, 20% discount rate, 15 years = $1/(1 + 0.20)^{15} = 0.065$
 2nd normal-efficiency motor cost = \$2 700 × FWF × PWF = \$316
 Present worth of 1st and 2nd motor costs = \$2 700 + \$316 = \$3 016

The present worth of 30 years of operating costs is estimated using the present worth annuity factor, PAE. It is assumed that electricity rates will escalate at the rate of inflation (4%). In order to use the present worth annuity factor, the

discount rate must be adjusted for the effects of inflation. A “real” discount rate that is netted of inflation is defined as follows:

$$\frac{(1+i) \times (1+f)}{1}$$

where

i = The cost of money used (in this case, the discount rate = 20%)
 f = The rate of inflation (in this case, 4%)

Thus

$$\frac{(1+0.20) \times (1+0.04)}{1} = 0.154$$

Present worth annuity factor for 30 years =

$$\frac{(1+0.154)^{30} - 1}{0.154 \times (1+0.154)^{30}} = 6.41$$

Present worth of operating cost, Option 1= PAF $\times$ annual operating costs

$$= 6.411 \times \$23\,400 = \$150\,017$$

Present worth of operation cost, Option 2= PAF $\times$ annual operating costs

$$= 6.411 \times \$23\,100 = \$148\,094$$

Present worth of operating cost, Option 3= PAF $\times$ annual operating costs

$$= 6.411 \times \$22\,400 = \$143\,606$$

The total life cycle cost of each option is the sum of the present worth of the capital and installation cost of each option and the present worth of operating costs for each option.

Total life cycle cost, Option 1= PW capital and installation + PW operating costs

$$= \$2\,203 + \$150\,017 = \$152\,220$$

Total life cycle cost, Option 2= PW capital and installation + PW operating costs

$$= \$2\,569 + \$148\,094 = \$150\,663$$

Total life cycle cost, Option 3= PW capital and installation + PW operating costs

$$= \$3\,016 + \$143\,606 = \$146\,622$$

The life cycle cost analysis shows that Option 3 has the lowest life cycle cost of the three options considered. Based on this analysis, the plant engineer orders the purchase of high-efficiency motors to replace the failed motor.

3.4.3.1 Relationship to other economic methods

The life cycle cost calculations illustrated are consistent with respect to the considerations described in 3.3.1 and 3.3.2.