

IEEE Recommended Practice for Energy Conservation and Cost-Effective Planning in Industrial Facilities

The IEEE Bronze Book, the newest addition to the IEEE Color Book series will be of great value to power-oriented engineers and designers associated with industrial and commercial facilities.

Energy conservation and cost-effective planning are addressed in the areas of 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.

The topics covered in this recommended practice include:

- The affects of fuel cost on electric energy cost
- Organization and Management commitment to a successful energy conservation effort
- Economic analysis for evaluating energy alternatives and motor and transformer loss evaluation
- Load management through demand control and energy control techniques
- The importance of proper equipment application, and design and maintenance of electrical systems
- Metering electrical energy and measuring performance of electrical systems
- New and existing lighting systems
- Energy-saving potential and economic benefits of cogeneration

IEEE Recommended Practice for Energy Conservation and Cost-Effective Planning in Industrial Facilities



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IEEE Recommended Practice for Energy Conservation and Cost-Effective Planning in Industrial Facilities

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of the
IEEE Industry Applications Society**

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Foreword

(This Foreword is not a part of IEEE Std 739-1984, *IEEE Recommended Practice for Energy Conservation and Cost-Effective Planning in Industrial Facilities*.)

This recommended practice is the result of a six year effort by members of the Industrial Plants Power Systems Energy Subcommittee of the IEEE Industry Applications Society.

The purpose of the IEEE Bronze Book is to promote the concepts and practices of electrical energy conservation in the engineering community. This information was not addressed exclusively by any text available at the time, but rather was distributed among many sources. It has been approved by the IEEE Standards Board as an IEEE standards document to provide current information and recommended practices for energy conservation and cost-effective planning in industrial facilities.

This publication known as the Bronze Book is one of the present IEEE Color Book series sponsored by the IAS Industrial Power Systems Department. This IEEE Recommended Practice will complement and supplement the following color books prepared by the IEEE Industrial and Commercial Power Systems Department:

Recommended Practice for Electric Power Distribution for Industrial Plants (IEEE Red Book), IEEE Std 141-1976.

Recommended Practice for Grounding of Industrial and Commercial Power Systems (IEEE Green Book), ANSI/IEEE Std 142-1982.

Recommended Practice for Electric Power Systems in Commercial Buildings (IEEE Gray Book), ANSI/IEEE Std 241-1983.

Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems (IEEE Buff Book), IEEE Std 242-1975.

Recommended Practice for Industrial and Commercial Power System Analysis (IEEE Brown Book), ANSI/IEEE Std 399-1980.

Recommended Practice for Emergency and Standby Power for Industrial and Commercial Applications (IEEE Orange Book), ANSI/IEEE Std 446-1980.

Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems (IEEE Gold Book), ANSI/IEEE Std 493-1980.

Comments, corrections, and suggestions for the next revision of this publication are encouraged and should be submitted to the

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Comments on standards and requests for interpretations should be addressed to:

Secretary, IEEE Standards Board
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1. Introduction

1.1 General Discussion. IEEE Std 739-1984, IEEE Recommended Practice for Energy Conservation and Cost-Effective Planning in Industrial 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 conservation in industrial facilities. Most of the material herein is also applicable to commercial facilities. It has been prepared by engineers and designers on the Energy Subcommittee of the IEEE Industrial Power Plant Systems Committee (IPPS) of the IEEE 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 dealing with 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.

1.2 Conservation. Energy conservation as treated in this recommended practice deals with 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.

1.3 Methodology. The methodology of conservation involves the use of the management tool commonly referred to as energy management. This has been elevated to a separate *discipline* or specialty. It often is even more confined by being emphasized within the conventional disciplines — electrical or mechanical. The term *energy engineer* will refer to the engineer performing duties in the energy area, whether full or part time.

1.4 Energy Management. Energy management, the more inclusive term for energy conservation, involves the following professions and fields:

- (1) Engineering
- (2) Management, organization
- (3) Economics
- (4) Financial analysis
- (5) Operations research (system analysis)
- (6) Public relations (selling conservation)
- (7) Environmental engineering

Some of the tools that are dealt with here are:

- (1) Meters and measurement
- (2) Demand and energy limiters
- (3) Highly efficient energy devices
- (4) Control systems — building management systems

While this recommended practice emphasizes electrical energy conserva-

tion, other forms of energy shall be treated. Section 8 deals with the combined efficient use of electrical and thermal energy (steam) in a highly efficient cost-effective manner. The text points out that the reduction of energy in one area can actually have a negative effect on the heat balance. For example, the reduction of thermostat temperature setting in large buildings in winter can cause excessive operation of the air-conditioning chillers.

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.

1.5.1 *Spectrum*, the basic monthly publication of the IEEE, covers all aspects of electrical and electronic engineering including conservation. This publication also contains references to IEEE books and other publications, technical meetings and conferences, IEEE groups, societies, 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.

1.5.2 *The Transactions of the Industry Applications Society* (IAS) contain papers presented to conferences, a number of which deal with energy conservation. All members of the IAS receive this publication.

1.5.3 Publications which specifically are oriented toward energy conservation include:

*Energy User News.*¹ A weekly news publication in tabloid format which covers the entire field of energy conservation

¹ Fairchild Publications, 7 East 12th Street, New York, NY 10003.

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 scoreboard is included.

NTIS — National Technical Information Service of the US Department of Commerce² is an abstract newsletter published weekly. Each year it contains abstracts of hundreds of articles relating to energy listed by subject. A purchase form for obtaining many of the articles is included with each issue.

1.5.4 The Association of Energy Engineers publishes several documents including the bimonthly *Energy Engineering* and the quarterly *Energy Economics Policy and Management*. In addition, the Association and the US Department of Energy sponsored a conference in 1981. The papers are available in the *Proceedings of the Fourth World Energy Engineering Congress*.³

1.5.5 Some other periodicals of a more general nature which are heavily involved with electrical energy conservation are:

Electrical Construction and Maintenance, 1221 Avenue of the Americas, New York, NY 10020.

Electrical Consultant, One River Road, Cob, CT 06807.

LD & A, Illuminating Engineering Society, 345 East 47th Street, New York, NY 10017.

Plant Engineering, 1301 South Grove Avenue, Barrington, IL 60010.

Power, 1221 Avenue of the Americas, New York, NY 10020.

Power Engineering, 1301 South Grove Avenue, Barrington, IL 60010.

Electric Light and Power, 1301 South Grove Avenue, Barrington, IL 60010.

Specifying Engineer, 51 South Wabash Avenue, Chicago, IL 60603.

1.5.6 Two technical periodicals which contain material of interest are:

Energy Management is directed at management in business and industry. It is published bi-monthly by Penton, 614 Superior Avenue West, Cleveland, OH 44113.

Plant Energy Management is published bi-monthly by Walker-Davis Publication, Inc, 2500 Office Center, Willow Grove, PA 19090.

1.5.7 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 conservation work.

1.6 **Standards and Recommended Practices.** A number of organizations in addition to the National Fire Protection Association (NFPA) publish documents which affect electrical design. Adherence to these documents can be written into design specifications.

The American National Standards Institute (ANSI) 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 US for technical standards of all types.

Underwriters' Laboratories, Inc (UL), is a nonprofit organization, operating

² 5285 Port Royal Road, Springfield, VA 22161.

³ PO Box 14227, Atlanta, GA 30324.

laboratories for investigation of materials and products, especially electrical appliances and equipment with respect to hazards affecting life and property.

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:⁴

Electrical Heating and Cooling Handbook.

A Planning Guide for Architects and Engineers

A Planning Guide for Hotels and Motels Electric Space-Conditioning.

Industrial and Commercial Power Distribution

Industrial and Commercial Lighting

The National Electrical Manufacturer's Association (NEMA) 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 which might affect the application of any equipment that he specifies.

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.

ANSI/IEEE Std 100-1984, IEEE Standard Dictionary of Electrical and Electronics, Terms.

ANSI/IEEE Std 315-1975, IEEE Standard Graphic Symbols for Electrical and Electronics Diagrams.

ANSI Y32.9-1972, American National Standard Graphic Symbols for Electrical Wiring and Layout Diagrams Used in Architecture and Building Construction.

The Electric Energy Association (EEA) publishes specifications and informative pamphlets for buildings with electric space conditioning.

The Building Officials and Code Administrations International, Inc (BOCA), is an organization which 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. The BOCA Basic Energy Conservation Code 11981 is a compilation of model energy conservation requirements from the BOCA Basic Building Code applicable in 1981.⁵

1.7 Industry Application Society (IAS).

The IAS is one of 31 IEEE groups and societies which specialize in various technical areas of electrical engineering. Each group or society conducts meetings and publishes papers on developments within its specialized area. The IAS presently encompasses 23 technical committees covering electrical engineering in specific areas (petroleum and chemical industry, cement industry, glass industry, industrial and commercial power systems and others). Papers of interest to electrical engineers and designers involved in the field covered by this text are, for the most part, contained in the Transactions of the Industry Applications Society of the IEEE.

⁴ 111 19th Street, Washington, DC 20036.

⁵ BOCA is located at 17926 Halsted Street, Hanewood, IL 60430.

1.8 IEEE Publications. The IEEE publishes several standards similar to the IEEE Bronze Book prepared by the Industrial Power Systems Department of the IEEE Industry Applications Society.⁶

[1] ANSI/IEEE Std 142-1982, IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems (IEEE Green Book).

[2] ANSI/IEEE Std 241-1983, IEEE Recommended Practice for in Commercial Buildings (IEEE Gray Book).

[3] ANSI/IEEE Std 399-1980, IEEE Recommended Practice for Power System Analysis (IEEE Brown Book)

[4] ANSI/IEEE Std 446-1980, IEEE Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications (IEEE Orange Book).

[5] ANSI/IEEE Std 493-1980, IEEE Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems (IEEE Gold Book).

[6] IEEE Std 141-1976, IEEE Recommended Practice for Electric Power Distribution for Industrial Plants (IEEE Red Book).

[7] IEEE Std 242-1975, IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems (IEEE Buff Book).

⁶ These documents are available from the Sales Department, IEEE Service Center, 445 Hoes Lane, Piscataway, NJ 08854.

[8] IEEE J2112-1-1973, Protection Fundamentals for Low-Voltage Electrical Distribution Systems in Commercial Buildings.

1.9 Governmental Regulatory Agencies

1.9.1 Actions of the United States government regulatory agencies are embodied in the *Federal Register*.⁷ 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.

1.9.2 The Department of Energy (DOE) sponsors experimental or demonstration projects through grants and other incentives. Reports are issued on such programs as, for example, the fluorescent lamp solid-state ballast under grant to Lawrence Berkley Laboratories of the University of California.

1.9.3 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 90-75 and ASHRAE 90-100⁸ are accepted as a basis for design of new buildings and existing buildings. While some states have accepted these standards almost verbatim, other states, such as New York, have issued their own equivalents. It is important to recognize which rulings are based on law in the locality under consideration.

⁷ This daily publication is available from the US Government Printing Office, Washington, DC 20402.

⁸ These documents are available from ASHRAE, Publication Sales, 1791 Tullie Circle, NE, Atlanta, GA 30329.

1.9.4 ASHRAE 90-75 and ASHRAE 90-100 were developed by the American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) in conjunction with members of the Illuminating Engineering Society (IES) to provide an energy budget. 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. These documents have legal status only where local authorities have incorporated their recommendations.

1.9.5 Where generation (except for emergency and standby purposes is involved) and especially where the resale and redistribution of energy for use by others are concerned, regulations of the Federal Energy Regulatory Commission (FERC) may apply. PURPA, the Public Utilities Regulatory Act of 1978, now under review by the courts, 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.

1.9.6 Public Service or Utility 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.

1.9.7 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 in the abundance of information being generated in the energy field.

(1) Read the aforementioned periodicals. Some are dedicated to energy only, while others can be scanned for energy articles.

(2) 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 deal with the subject in general or concentrate on special aspects. Sessions covering the subject are presented frequently by the organizations listed in 1.10 (3).

(3) Become active in the energy committees of societies such as the IEEE, IES, AIA (American Institute of Architects) and ASHRAE on a local or national basis.

(4) Read professional books and handbooks dealing with conservation. These will often be advertised or listed in the periodicals referred to above.

(5) Read advertising literature, which, although often biased, can provide an excellent guide to new equipment, its application and the basis of justification.

(6) If you are a manager, establish the programs, described in the following sections, 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 usually essential. 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 National Bureau of Engineering Registration to engineers who obtained their home-state license by examination. All engineering graduates are encouraged to start on the path to full registration by taking the engineers-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. The *energy engineer* in his work will often span several of the conventional disciplines and will often deal with other disciplines.

1.12.1 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. He 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 engineer will work directly with the architect. He shall cooperate with the safety engineer, fire-protection engineer, the 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 Specification Institute (CSI) where the energy conservation work of the electrical-mechanical engineering will usually fall in Chapter 15, Chapter 16 (electrical) and (if included) a 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 divided into a number of contracts, some of which may be awarded to contractors of different disciplines. Among items with which the designer will be concerned are: preliminary estimates, final cost estimates, plans, or drawings, specifica-

tions (which are the written presentation of the work), materials, manuals, factory inspections, laboratory tests, and temporary power. He may well 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.

1.12.2 The energy engineer is encouraged to proceed with care in making changes which 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:

- (1) Are lighting color changes acceptable and compatible?
- (2) Are workers uncomfortable in the changed ventilation conditions?
- (3) Is task lighting producing a gloomy environment?
- (4) Is machinery operating at reduced power because of voltage reduction drop-out in a brownout?
- (5) Is the area uncomfortably humid because of loss of reheat?
- (6) Is the building computer debugged?
- (7) Is a perfectly *good* lighting redesign producing a rash of headache and eye complaints?
- (8) Are the building tenants sharing in energy money 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. Today, a host of new tools described in the following sections are available to ease the work of the engineer in preparing a well

conceived, energy-conserving design.

1.13 Text Organization. The subsequent sections cover energy conservation in the following sequence of subjects:

1.13.1 Fuels. In addition to introducing conservation, this section covers the affect of fuel cost on electric energy cost.

1.13.2 Organizing for Energy Conservation. The proper organization and management commitment are prerequisites to a successful energy conservation effort.

1.13.3 Economics. This section provides several models for evaluating energy alternatives and motor and transformer loss evaluation. Electric rate structures are also explained.

1.13.4 Load Management. The use of demand control can reduce electric bills but not necessarily energy use. This section looks at demand control techniques but, more importantly, discusses energy control techniques.

1.13.5 Electrical Machines and 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.

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

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

1.13.8 Cogeneration. The concurrent use of steam 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.

1.14 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 are divided into three major categories — fossil, solar, and nuclear fuels.

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

(1) Coal is generally acknowledged as the United States' most plentiful fossil fuel resource. 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 have recently increased funding for coal research. Some new techniques are being explored for the use of coal; coal burning technology should improve 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 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.

(2) Natural gas is the cleanest burning fossil fuel, but it has the least proven reserves. Many parts of the country have experienced shortages of natural gas. Outright curtailments have often forced the shutdown of plants, schools, and commercial establishments.

The industry was highly regulated; however, the National Gas Policy Act (NGPA) initiated the process of deregulation. Interstate regulation of natural gas by the Federal government was accomplished by fixing the price at the well head. Intrastate regulation was done by state utility commissions because natural gas companies generally had exclusive distribution and selling rights in a given geographical area.

Natural gas presents few air pollution problems and is probably the least capital intensive of the fossil fuels. Lack of availability remains its chief disadvantage, although deregulation should encourage exploration and the use of wells that were previously thought to be uneconomical to operate. However, US reserves will probably be depleted in two decades at current consumption rates.

The NGPA will cause gas prices to keep pace with the rate of inflation. Deregulation is scheduled for completion by 1987. For industrial gas customers, one negative aspect of the NGPA is that interstate pipeline and distribution companies shall price the gas "incrementally;" that is, the price of new gas shall be passed on to the large user as opposed to all users of gas. In summary, gas prices should rise as the rate of inflation, but deregulation will adversely affect the price if the supply fails to keep pace with demand.

(3) 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. While the United States 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 are well documented. In summary, the price of foreign oil has accelerated at a rate which has no relationship to the laws of supply and demand. The US demand for oil has outstripped our domestic supply. Without foreign oil, we would deplete our reserves in approximately two decades. The US is confronted, therefore, with a problem concerning the use of oil now and in the immediate future. Oil prices will rise faster than inflation.

1.14.2 Solar. Solar energy encompasses the use of the sun's radiation to produce electricity or as a heating and cooling source. Solar energy has gained attention because of governmental and general public pressure, but it has not been an economically viable energy resource. More research and expanded use of solar energy, even in situations where it is uneconomical, should improve the technology and lower capital costs.

The five primary types of solar energy include: 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.

(1) Photovoltaics are probably the most interesting means of converting solar energy into electricity. There are currently three drawbacks to photovoltaic that make widespread use doubtful. First, they are only 15% efficient while costing 10 to 100 times more per kilowatthour than other methods. Second, a very large area is required for collection of the energy. A 132 MW demonstration plant in Phoenix, Arizona, uses 640 acres or an equivalent of a one-mile by one-mile plot. Third, the system can only generate electricity on sunny days.

A very intriguing proposal uses an earth orbiting solar station to collect the light and then converts the energy to microwaves beamed to an earth-based receiving station. This concept allows 24 h generation without any negative effects of weather. While much more efficient, the system requires significant amounts of land for the receiving station and is much more expensive than earth-based photovoltaic. The system is apparently safe, but the affects of the microwave beam on radio, TV, and wild-life have not been determined.

(2) 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 output is restricted to daylight hours.

(3) Wind conversion has been successfully used to generate small amounts of power. The drawbacks with wind genera-

tion include noise, radio and TV interference, very fast tip speeds (60–80 ft/s) and size limitation. The NASA device in Sandusky, Ohio, has 50 ft diameter blades to power a 225 kW generator. The NASA device operates when the wind speed is between 7 and 30 m/h, which is typical. Higher electrical output is being generated in windmill farms containing many mills.

(4) 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.

(5) 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.

1.14.3 Nuclear. 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 United States 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.

1.14.4 Conclusion. 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 United States. 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.

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2. Organizing for Energy Conservation

2.1 Introduction. To understand the energy consumption patterns in the industrial sector, it is important to understand the applications of energy in industrial processes. Industrial energy applications are grouped into six major types.

2.1.1 Types of Industrial Energy Applications

(1) *Space Conditioning.* Energy used directly for heating or cooling an area for comfort conditioning without first being converted to steam or hot water.

(2) *Boiler Fuel.* This is subdivided into space conditioning and process energy, depending on how the steam or hot water from the boiler is utilized.

(3) *Direct Process Heat.* Energy used to heat the product being processed, for example, for kilns, reheat furnaces, etc, excluding energy used in boiler steam or hot water.

(4) *Feedstock.* Fuel used as an ingredient in the process.

(5) *Lighting*

(6) *Mechanical Drive.* Motors used for

pumps, crushers, grinders, production lines, etc possess this mechanical drive.

Energy savings can occur by improving the efficiency of energy conversion processes, by recycling the waste energy or, by reusing the 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. However, other less energy intensive industries have not found the use of energy recovery equipment economically advantageous.

Two economic incentives exist for the development of an energy conservation program on a plant-by-plant basis: (1) the savings realized by reducing energy use,

and (2) preventing economic losses by minimizing the probability of fuel supply curtailment.

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

2.1.2 Energy Saving Methods. The ways in which energy can be saved are grouped into four general categories:

(1) *Housekeeping Measures.* Basically 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.

(2) *Equipment and Process Modifications.* These can either be applied to existing equipment (retrofitting) or be 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 a process with one using less energy.

(3) *Better Utilization of Equipment.* This can be achieved by carefully examining the production processes, schedules, and operating practices. Typically, industrial plants are multi-unit, multi-product installations which 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.

(4) *Reduction of Losses in the Building Shell.* Reduction in heat loss is achieved by adding insulation, closing doors, reducing exhaust, and by utilizing process heat, etc.

Management shall 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 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 sections 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 conservation 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 aware of the key persons who make decisions. These key persons shall be convinced of the positive merits of an energy conservation 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 conservation program are:

(1) 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.

(2) Obtain people commitment. People in all levels of the organization should be involved in the program. Ideas should be encouraged with rewards for cooperation. 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.

(3) Set up a communication channel. Use the channel to report to the organization the results, high achievers, rewards, etc. Use the channel to advertise the program and to encourage cooperation.

(4) Change or modify the organization to give authority and commensurate responsibility for the conservation effort and develop a program.

(5) 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 conservation programs. This plan should also: define the responsibilities of the energy conservation 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 be in terms of energy and not cost, while taking into consideration the effect of diminishing returns.

The energy team should at least consist of representatives from each major facility or department; 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 determine by an energy audit 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 data base 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 shall be covered. Power bills shall be reviewed considering the following quantities, when available: kilowatthours, kilovarhours, kilowatt demand, kilovoltampere demand, power factor, days in billing cycle, reading date, weather conditions, and production factors affecting power consumption. The plant should be toured to discover 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.

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. Six categories for energy use should be analyzed as the tour is conducted. These six categories are as follows:

- (1) Lighting: interior, exterior, natural, and artificial
- (2) The Heating, Ventilating and Air Conditioning (HVAC) system and the heating and cooling effects of conduction, convection, and radiation
- (3) Motors and drives
- (4) Processes
- (5) Other electrical equipment — trans-

formers, contactors, conductors, switchgear, etc)

(6) Building shell, in terms of infiltration, insulation, and transmission.

Within each of these categories, five basic conservation concepts shall be considered:

(a) General housekeeping — turn off unused equipment, close doors, redirect heat or light, etc)

(b) Process or physical changes — move the desk closer to the window

(c) Better use of equipment or purchase of new equipment — run two batches instead of one

(d) Obvious misapplication of equipment — [150 fc (1600 lx) in a storage area or a 10-ton crane to move a 100 lb carton]

(e) Maintenance — change filters, clean lights, lubricate motors and drives

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

(1) 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.]

(2) Is the fixture proper for directing the light where it is needed?

(3) Is the reflection good?

(4) Is the color right for the task?

(5) Is the fixture too high or too low?

(6) Can task lighting be used effectively?

(7) Is good use being made of available natural light?

(8) Can desks or machines be grouped by task light required?

(9) Are lights and fixtures cleaned periodically?

(10) Are lights turned off when not in use?

(11) How many fixtures can be turned off by a single switch?

(12) Who turns lights off?

(13) Who uses the space and how often?

(14) Can a different, lower wattage bulb be used in the fixture?

(15) Do the surfaces reflect or absorb light?

(16) Are the lights strategically located?

(17) Does the fixture location cause glare?

(18) Can light be used to heat?

(19) Can more efficient light sources be used?

(20) Can timers or photocells be effectively used?

2.3.2 Heating, Ventilating and Air Conditioning (HVAC). Key factors in evaluating and better utilizing the HVAC system are as follows:

(1) Are there obstructions in the ventilating system?

(a) Do filters, radiator fins, or coils need cleaning?

(b) Are ducts, dampers, or passages and screens clogged?

(2) Is the wrong amount of air being supplied at various times?

(a) Are dampers stuck?

(b) Is exhaust or intake volume too high or too low?

(c) Are all dampers functioning in the most efficient manner?

(3) Can the system exhaust only the area needing ventilation?

(4) Can the system intake only the amount required?

(5) Can air be recycled rather than exhausted?

(6) Can the intake or exhaust be closed when the facility is unoccupied?

(7) Can the system be turned off at night?

(8) Is the temperature right for area's

use? — 40 °F-50 °F can be good for storage

(9) Can temperature setback be used effectively?

(10) Will variable speed drive be more efficient?

(11) How many fixtures can be turned off by a single switch?

(12) Is solar energy being effectively utilized?

(a) Light but minimum heat in summer

(b) Light and heat in winter

(13) Can waste heat be used?

(14) Are belts tight?

(15) Are pulleys and drives properly maintained and lubricated?

(16) Is the refrigerant proper?

(17) Is waste heat utilized?

(18) Can heat be redirected?

(19) Is the proper system being used?

(20) Is there too much or too little ventilation?

(21) Can the natural environment be used more effectively?

(22) Are doors, windows, or other openings letting out valuable heat?

(23) Can weatherstrip, caulk, or other leaks be repaired?

(24) Can additional insulation be justified?

(25) Can all hooded exhaust systems have their own air supply or can they be used as part of the exhaust requirement for the building?

(26) Is the blower cycled or run continuously?

2.3.3 Motors and Drives. Because motors use nearly 70% of the electrical energy consumed in the US, they provide great opportunity for reducing energy waste. The following questions point to very common kinds of waste:

(1) Does the motor match the load?

(2) Can the motor be stopped and then restarted rather than idled?

(3) Is the motorized process needed at all? Can it be done by hand?

(4) Who lubricates the motor and associated drives? Is this done at the proper interval?

(5) Can motor heat be recycled?

(6) What type of drive is used? Is it the most efficient?

(7) What is the voltage and is it balanced?

(8) Can the motor be cleaned to lower heat buildup?

(9) How is load adjusted?

(10) Will two (or more) motors in tandem work better?

(11) Is the motor well maintained and in good condition? Are there any electrical leaks to ground? Is it in a wet environment?

(12) Who turns the motor off and on? How often?

(13) How efficient is the motor?

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

(1) Can equipment or processes be grouped together to eliminate the transportation of the equipment or material in process?

(2) Is the temperature too high?

(3) Does heat escape? Can insulation be used effectively?

(4) Can the heated energy be recirculated for comfort, process heat or cogeneration? Can it be exhausted for summer comfort?

(5) Is preheat required?

(6) Can the process be staged or interlocked?

(7) Is the product heated, cooled and then reheated again? Therefore, is a continuous process more appropriate?

(8) Can the processes be lined up for more effective use of equipment?

(9) Are the drives, bearings, etc lubricated?

(10) Can the conveyor system be eliminated or modified?

(11) Can hot areas be isolated from cold areas?

(12) Is one large or many small motors better?

(13) What equipment can be turned off at night?

(14) Would two or three shifts be more efficient?

(15) Is any equipment kept idling rather than shut off when in hold or waiting?

(16) Are screens cleaned, dampers checked for proper operation of pollution controls, and are they maintained at proper intervals, etc?

(17) Is compressed air made in two or three stages? Is a hold tank being used and is pressure too high?

(18) Is process water too hot?

(19) Can fluid be recirculated?

(20) Is the fluid cooled too much?

(21) Is the hot water heater close to hot water use?

(22) Is the process exhaust higher than required for safety or quality, or both?

(23) Is hot and cold piping insulated where appropriate?

(24) Is temperature controlled so that only necessary heat is added?

(25) Is heat supplied or added at the point of use or is it transmitted some distance?

2.3.5 Other Electrical Equipment. There is a significant amount of electrical equipment that is taken for granted or rarely noticed. The list below asks some key questions regarding efficiency:

(1) Are the transformers required?

(2) Is the transformer too hot? (Good heat source.)

(3) Can the transformer be turned off when not in use?

(4) Are wiring connections tight? Improper voltage, unbalanced voltage, and excess heat can result from a bad connection.

(5) Can heat from the switchgear room be utilized? Remove this heat during the summer.

(6) Are voltage taps in the proper position?

(7) Are heaters applied properly?

(8) Can heaters be turned off at times?

(9) Are contactors in good working order?

(10) Is equipment properly bonded and grounded?

(11) Are conductors sized properly for the load?

(12) Is the power factor too low?

2.3.6 Building Environmental Shell.

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

(1) Is allowance made for transition from cold to hot areas and vice versa with an air curtain or vestibule?

(2) Can a wind screen keep air infiltration down?

(3) Is the proper level of insulation applied?

(4) Can full advantage of solar heat be taken? Remove effect in summer.

(5) Is automatic door closing appropriate?

(6) Can covered loading and unloading areas be utilized to keep heat in?

(7) It is possible to caulk, weather-strip, glaze, or close-off windows?

(8) Can double or triple pane glass be used?

(9) Is a small positive pressure used to keep out drafts?

(10) Can areas be staged in progressively cooler or warmer requirements?

(11) Would an air screen, radiant heater, etc be more effective?

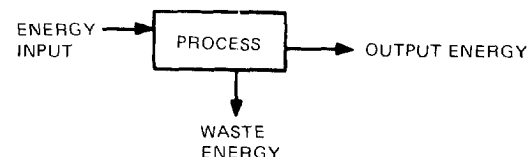
(12) Are dock seals used on overhead doors?

2.3.7 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 section provides many areas for improved efficiency, a detailed analysis and engineering design by a competent consultant will be required. The final design will 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).

2.3.8 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 Fig 1. Energy is input to a system which

Fig 1
Energy Balance



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.

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

- (1) Can waste heat be recovered to generate steam or to heat water or a raw material?
- (2) Can a process step be eliminated or modified in some way to reduce energy use?
- (3) Can an alternate raw material with lower process energy requirements be used?
- (4) Is there a way to improve yield?
- (5) 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 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.

2.4 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 turning off lights to new long-range technologies.

The equipment used in manufacturing 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:

- (1) Calculate annual energy savings for each project.
- (2) Project future energy costs and calculate annual dollar savings.
- (3) Estimate the cost of the project, including both capital and expense items.
- (4) Evaluate investment merit of projects using measures such as return on investment, etc.
- (5) Assign priorities to projects.
- (6) Select conservation projects for implementation and request capital authorization.
- (7) Implement authorized projects.

Section 2.3 describes examples of elec-

trical energy conservation opportunities. 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 counter-productive. For instance, the proposed change may cause existing equipment to exceed operating limits.

2.5 Energy Monitoring and Accounting.

An effective energy conservation program requires feedback on performance. Since company-wide energy conservation is relatively new at most companies, the best techniques are not yet apparent. However, the ensuing paragraphs describe some guidelines that have evolved.

An energy accounting system is essential for control and evaluation of an energy conservation program. Different uses and applications require different accounting and measuring techniques. In many cases, periodic or irregular fuel deliveries or meter readings will not provide adequate information to determine the variation of energy use with daily, weekly, or monthly production cycles, or with seasonal meteorological changes. In other cases, energy in the form of fuels, electricity, and process steam will be used in two or more different major applications in the plant. 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.

A number of very useful methods to maintain energy conservation performance in plants and offices worldwide are described in [1].⁹ Other established effective methods are given in [3], [4], [5], and [6]. 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, [1] states that energy conservation is monitored using the activity method, the energy-rate method, the variable energy-rate method, or tracking charts.

2.5.1 Percent Reduction Energy Rate Method. This reduction is determined by comparing the project's product energy rate, expressed in Btu/lb with the existing plant's product energy rate. An example is shown in Table 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 inplant utilities such as steam,

⁹ The numbers in brackets refer to the numbers of the Bibliography in 2.8.

Table 1
Product Energy Rate

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

refrigeration, compressed air, and cooling water. All energy, purchased or generated has to be expressed in the same units, for example, Btu. Likewise, the manufacturing department is given credit for usable energy which is exported such as condensate and steam.

2.5.2 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.

(1) It is a means of information exchange on energy-saving ideas.

(2) It provides an opportunity to monitor energy conservation capital requirements versus energy savings on projects.

(3) It assists in an energy-awareness program in the engineering department.

This report is prepared by a project participant when he incorporates an energy-saving idea or innovation that will reduce energy requirements. The guideline for an energy-saving 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.

2.5.3 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. A similar report can also be prepared expressing the savings in Btu and costs — statistics that are most useful for internal communications and external publicity.

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 re-

Table 2
Activity Method Report

XYZ Manufacturing Co Energy-Conservation Results Activity Method (% Energy Savings)					
Plant	3 Qtrs	4th Qtr	Year 0 Total	Planned Activities Year 1	Year
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

Table 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 (× 10 ⁶ Btu)	Total Production (× 10 ⁶ lb)	Total Energy (× 10 ⁶ Btu)	Comparison Base Period Energy (× 10 ⁶ Btu)	% Reduction Energy Con- sumption Rate
	1	2	3	4	5	3 × 4 = 6	7
A	200	10 000	50	300		15 000	
B	10 000	30 000	3	12 000		36 000	
C	2000	20 000	10	3000		30 000	
D	3000	60 000	20	6000		120 000	
	15 200	120 000		21 300		201 000	
Adjustments to base: new products (+) or discontinued products (-) after Year 0 (base).							
E (Year 1)	1000	10 000	10	2000		20 000	
F (Year 2)	1000	5 000	5	1000		5 000	
	2000	15 000		3000		25 000	
Total products	17 200	135 000		24 300	208 000	226 000	7.5*
Adjustments for en- vironmental and OSHA	Base				(1000)		
Adjusted grand total	17 200	135 000		24 300	208 000	226 000	8.0*

*% Reduction energy consumption rate = $\frac{(\text{Column 6}) - (\text{Column 5})}{(\text{Column 6})} \cdot 100 = (\text{Column 7})$.

duction in energy rate, Btu per pound of products, because the savings are annualized.

2.5.4 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 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 pur-

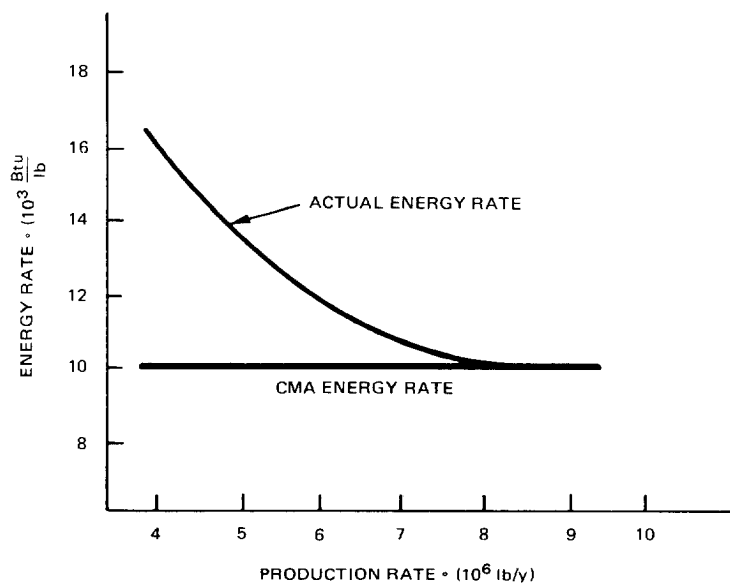
chased by the plant, excluding feed-stock energy. The comparison base period energy for each product is calculated using the base year product energy rate times the weight of the product manufactured in the current year.

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.

2.5.5 Variable Energy-Rate Method. Many variables need to be considered in a conservation monitoring method, including:

- (1) Changes in energy rate as production rate varies. See Figs 2 and 3.
- (2) Product energy requirement

Fig 2
Change in Production



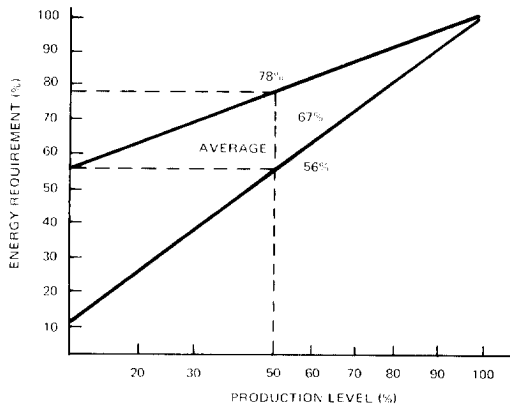


Fig 3
Energy Production

changes resulting from ambient temperature changes during the year.

(3) Changes in raw material quality.

(4) Changes in the plant heat balance that may cause the process to operate turbine drives instead of motor drives, and vice versa.

(5) Minor changes in product quality or specifications for different customers.

(6) A change in the equipment or process to increase output.

The product energy rate versus production-rate curve in Fig 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 Fig 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.

2.5.6 Tracking Charts. The tracking charts in Fig 5 can be used to establish trends in energy usage resulting from conservation, maintenance or the lack thereof, and operational techniques. Tracking charts are a speedy current technique used to track department and total plant production, purchased energies, generated utilities, and product energy rates. Also, tracking charts can monitor trends in conservation, energy usage, and potential problem areas.

Two time frames are typically used. Short periods (shift to daily) are used to review performance with shift operating personnel for quick feedback on operational performance. These usually span a month or so. Weekly to monthly period charts provide data that tend to average fluctuations in energy usage, and consideration is given to trends over a longer time. Any analysis of tracking charts shall take into consideration production rate and the effect it has on energy usage.

2.6 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, distri-

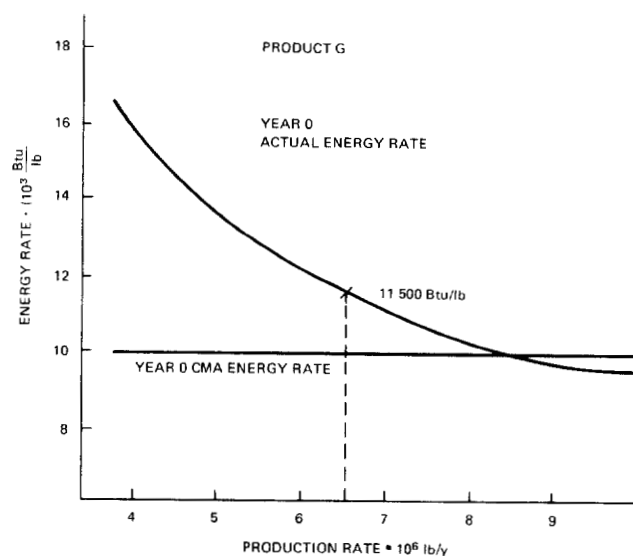


Fig 4
Actual and CMA Energy Rate
Versus Production Rate

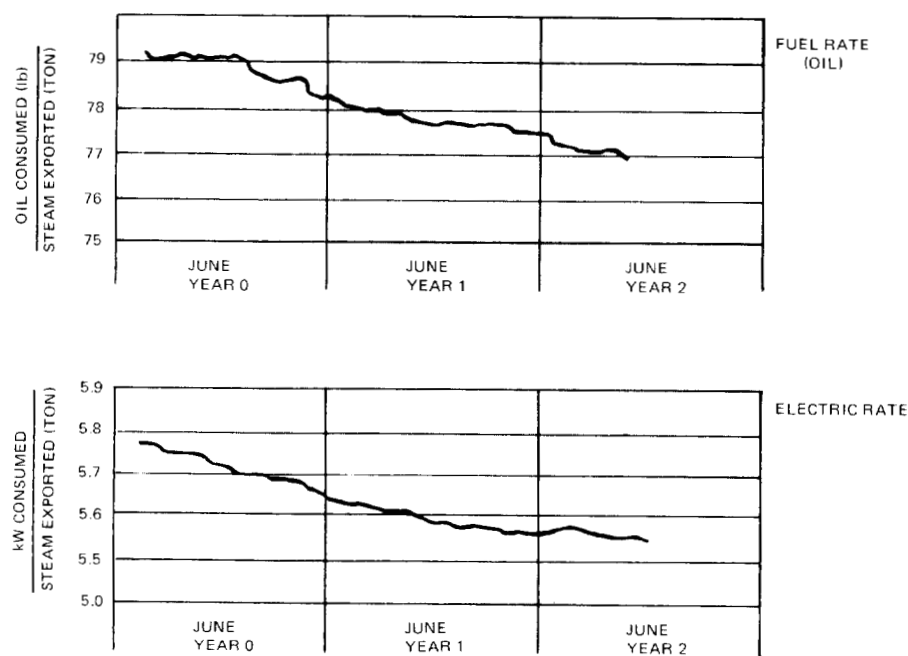


Fig 5
Tracking Chart

bution 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 idea, 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 lists.

2.7 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 US 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 direction required. An energy management function gives the line manager the tools to get the job done. Engineers shall inform upper management regarding energy use and costs, future energy supply cost and availability, and the level of savings possible. The engineer shall then convince management of the need for alternative solutions which should be pursued.

Obtaining participation from key local plant operators is a prime ingredient

to energy conservation success since they know where the energy leaks occur and generally are in a position to act fast. However, top management shall give them the monetary and technical resources required.

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3. Translating Energy into Cost

3.1 Introduction. The use of economic analysis is critical to the conservation program, because the monetary savings can significantly influence management decisions. The engineer shall, therefore, be able to translate his proposal(s) into monetary values (that is, expenditures versus savings). This section 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 his energy program and to determine the best choice among alternatives. This determination shall include understanding payback periods, understanding the time value of money, and weighing 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 monetary 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 (investment)*. Since an item is usually worth less as it ages the value is depreciated over its life. A piece of equipment has a *salvage 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, debugging costs, etc. Indirect costs (overheads) are monetary expenditures that cannot be directly assigned to a project such as 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, and the simplest method is *straight-line depreciation*. In straight-line depreciation, the annual depreciation is merely the capital cost divided by the estimated life.

There are two *lives*, the *book life* and the *expected (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 (energy), operation/maintenance, labor, taxes, and other recurring costs.

The fuel cost depends on the amount, quality, rate of use, and the tariff (rate schedule). The maintenance cost includes both routine work and purchase of parts, such as the periodic relining of boilers.

3.3 Time Value of Money

3.3.1 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 he 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 section will develop conversion factors that translate future dollars or payments into their present values and vice versa.

3.3.2 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 one year) 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 monthly 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 section, it is assumed that the investments are made at the beginning of the year and the ex-

penditures are made at the end of the year. Hence, \$1.00 invested now at a 10% annual interest rate will grow to \$1.10, at the end of the first year, but \$1.00 in operating and expense dollars will have a \$0.91 present value ($1.00 \cdot 1/1.1 = 0.91$). The present worth is the value at year zero 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:

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

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

$$\text{PW} = \text{PWF} \cdot \text{FW}$$

where

PW = present worth

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 5 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 \$100 000 now. To compare the alternatives, the \$120 000 future amount is converted to today's dollars.

Alternate A

Present: = \$10 000 PW

Future: = $\frac{1}{(1 + 0.12)^5} \cdot 120\,000$

= 68 100 PW

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. Ignoring the time value of money would have led to a 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

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

where

AP = annuity amount
(or equivalent annual payment)

Suppose the induction heater in the previous example had an energy cost of \$20 000 per year but the new unit only cost \$15 000 per year to operate.¹⁰ The

¹⁰ Operating costs commonly include maintenance, refurbishing, etc, but in this simplified example, only energy is considered.

annuity factor will provide a base of comparison by including the annual energy cost as a single present worth amount. While the net penalty 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 =

$$\frac{(1 + 0.12)^5 - 1}{0.12(1 + 0.12)^5} \cdot \$20\,000 = 72\,100 \text{ PW}$$

Total: \$150 190 PW

Alternate B

Current capital investment \$100 000 PW

Future energy costs =

$$\frac{(1 + 0.12)^5 - 1}{0.12(1 + 0.12)^5} \cdot \$15\,000 = 54\,000 \text{ PW}$$

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

$$\text{FWF} = (1 + i)^n$$

$$\text{FW} = \text{FWF} \cdot \text{PW}$$

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

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

and

$$\text{FW} = \text{FAF} \cdot \text{AP}$$

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.

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

and

$$\text{AP} = \text{UAF} \cdot \text{PW}$$

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 or

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

The preceding factors are summarized in Table 4. However, most studies will use only the present worth of a single future amount and the present worth of an annuity factor. The next section describes the use of these factors in an economic analysis of energy options.

3.4 Economic Models. 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, use of the time value of money may not be required. 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 turn 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 sections detail the various modeling methods.

3.4.1 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.

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 com-

Table 4
Time Value Factors

Symbol	Noun 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	$PWF = \frac{1}{(1+i)^n}$
SAF	Sinking fund annuity factor	Converts a future amount into an equivalent annuity	$SAF = \frac{1}{(1+i)^n - 1}$

*The two symbols have the following definitions:

n = the number of years in the evaluation period

i = the interest rate or other cost of money factor used