

IEEE Recommended Practice for Electric Systems in Health Care Facilities

Sponsor

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

Approved 21 March 1996

IEEE Standards Board

Abstract: A recommended practice for the design and operation of electric systems in health care facilities is provided. The term “health care facility,” as used here, encompasses buildings or parts of buildings that contain hospitals, nursing homes, residential custodial care facilities, clinics, ambulatory health care centers, and medical and dental offices. Buildings or parts of buildings within an industrial or commercial complex, used as medical facilities, logically fall within the scope of this book.

Keywords: anaesthetizing, clinical, critical branch, emergency system, equipment system, essential electrical system, examination, fire alarm, ground-fault circuit-interrupter, ground-fault protection, grounding, life safety branch, medical, nurse call, patient care, recovery, safety, standby generator, surgical, transfer switch, treatment, wet location

First Printing
January 1997
SH94446

The Institute of Electrical and Electronics Engineers, Inc.
345 East 47th Street, New York, NY 10017-2394, USA

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ISBN 1-55937-772-0

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Introduction

(This introduction is not a part of IEEE Std 602-1996, IEEE Recommended Practice for Electric Systems in Health Care Facilities.)

IEEE Std 602-1996, IEEE Recommended Practice for Electric Systems in Health Care Facilities, commonly known as the IEEE White Book, is written primarily for the practicing electrical design engineer who may have limited experience with health care facilities and for hospital operating personnel. It will also be useful for those who supply products and services for health care facilities. While the text deals with a broad range of topics relevant to the design and operation of health care facilities, it focuses on those aspects of facility design and operation that are unique to health care facilities. These include patient electrical safety, patient care issues, continuity of electric service, and a reliable source of power to sensitive computer-based clinical and biomedical equipment. The text also touches on communication and alarm systems that are unique to the health care facility.

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, 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 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).

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IEEE Recommended Practice for Electric Systems in Health Care Facilities

Chapter 1 Overview

1.1 Scope and general discussion

IEEE Std 602-1996, IEEE Recommended Practice for Electric Systems in Health Care Facilities, commonly known as the IEEE White Book, is published by the Institute of Electrical and Electronics Engineers (IEEE) to provide a recommended practice for the design and operation of electric systems in health care facilities. It has been prepared on a voluntary basis by design engineers, health care end users, as well as electrical and medical manufacturers functioning as the White Book Working Group within the Power Systems Design Subcommittee of the Power Systems Engineering Committee.

This recommended practice will probably be of greatest value to the power oriented engineer with limited health care experience. It can also be an aid to all engineers responsible for the electrical design of health care facilities. However, it is not intended as a replacement for the many excellent engineering texts and handbooks commonly in use, nor is it detailed enough to be a design manual. It should be considered a guide and a general reference on electrical design for health care facilities.

1.2 Health care facilities

The term “health care facility,” as used here, encompasses buildings or parts of buildings that contain hospitals, nursing homes, residential custodial care facilities, clinics, and medical and dental offices. Buildings or parts of buildings within an industrial or commercial complex, used as medical facilities, logically fall within the scope of this book. Thus the specific use of the building in question, rather than the nature of the overall development of which it is a part, determines its electrical design category. Today’s health care facilities, because of their increasing size and complexity, have become more and more dependent upon safe, adequate, and reliable electrical systems. Every day new types of sophisticated diagnostic and treatment equipment, utilizing microprocessors or computers, come on the market. Many of these items are sensitive to electrical disturbances and some require a very reliable power source. Invasive medical procedures such as cardiac catheterization have become routine in today’s hospital. Such procedures make electrical safety extremely important. Moreover, new medical and surgical procedures are constantly being developed. In addition to the special safety and reliability requirements, health care facilities have unique life safety and communication requirements, because patients are generally unable to care for themselves or

evacuate themselves in the event of an emergency. For these reasons, perhaps no area of design or construction is changing as fast as health care facilities.

1.3 IEEE publications

The IEEE publishes several standards similar to the IEEE White Book, prepared by the Industrial Power Systems Department of the IEEE Industry Applications Society.¹ The following standards may be useful for anyone designing or operating a health care facility:

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 446-1987, 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 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).

IEEE Std 241-1990, commonly known as the IEEE Gray Book, will be of particular importance as a reference book to the hospital designer because of the many similarities between commercial buildings and health care facilities.

¹IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331.

1.3.1 Industry Applications Society

The IEEE is divided into 35 groups and societies that specialize in various technical areas of electrical engineering. Each group or society conducts meetings and publishes papers on developments within its specialized area. The Industry Applications Society (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). The Power Systems Engineering Committee, which has balloting authority for the IEEE White Book, is part of the Industrial and Commercial Power Systems Department of the IAS. Papers of interest to electrical engineers and designers involved in the field covered by the IEEE White Book are, for the most part, contained in the *Transactions* of the IAS. Individuals who desire to participate in the activities of the committees or working groups in the preparation or revisions of the White Book or other Color Books should contact the IEEE Standards Department, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855.

1.3.2 Engineering in medicine and biology society

Another IEEE group of interest to the electrical engineer involved in health care facility design is the Engineering in Medicine and Biology Society (EMBS). The EMBS *Transactions* and the EMBS *Magazine* include articles on the physiological effects of electrical shock and other subjects pertinent to electrical safety. Articles dealing with electrical equipment and instrumentation also appear in the EMBS *Transactions*.

1.4 Professional registration

Most regulatory agencies require that design for public buildings be prepared by 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 Council of Examiners for Engineering and Surveying (NCEES).

To facilitate obtaining registration in different states by reciprocity, a national professional certificate is issued by the National Bureau of Engineering Registration² 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 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.

Clinical engineering certification is available through an international commission. When available, the hospital's clinical engineer should be involved in the electrical design process.

²P.O. Box 1686, Clemson, SC 29633-1686.

1.5 Codes and standards

1.5.1 National Electrical Code® and other NFPA standards

The electrical wiring and design recommendations in the National Electrical Code® (NEC®) (NFPA 70-1996) are vitally important guidelines for health care facility engineers. Article 517 of the NEC deals exclusively with installation criteria for health care facilities. The NEC is revised every three years, and care should be taken to use the edition that is current and adopted by the authority having jurisdiction of enforcement (AHJ) at the time of construction. The NEC is published and available from the National Fire Protection Association (NFPA).³ It does not represent a design specification but only identifies minimum requirements for the safe installation and utilization of electricity on the premises. The introduction to the NEC, Article 90, covers purpose and scope, and describes the AHJ's role in interpreting and enforcing the code. The *Handbook of the National Electrical Code®*, sponsored by the NFPA, contains the complete NEC text plus explanations. This book is edited to correspond with each edition of the NEC.

NFPA 99-1996, Health Care Facilities, addresses performance and testing criteria for electric systems in health care facilities as well as requirements for medical gas systems; heating, ventilation, and air conditioning systems; laboratories; and other topics of interest to health care designers. Approximately two thirds of NEC Article 517 is extracted from NFPA 99-1996.

The NFPA publishes the following related documents containing requirements on electrical and medical equipment and systems:

NFPA 20-1993, Installation of Centrifugal Fire Pumps.

NFPA 53-1994, Fire Hazards in Oxygen-Enriched Atmospheres.

NFPA 70B-1994, Electrical Equipment Maintenance.

NFPA 70E-1995, Electrical Safety Requirements for Employee Work Places.

NFPA 72-1993, Protective Signaling Systems.

NFPA 75-1992, Electronic Computer/Data Processing Equipment.

NFPA 77-1993, Static Electricity.

NFPA 101-1994, Life Safety Code.

NFPA 101HB94, Life Safety Code Handbook, 1994 edition.

³The NEC is available from Publication Sales, National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101.

NFPA 110-1993, Emergency and Standby Power Systems.

NFPA 111-1993, Stored Electrical Energy Emergency and Standby Power Systems.

NFPA 780-1992, Lightning Protection Code.

NFPA FPH1791, Fire Protection Handbook, 1991 edition.

The NEC and other selected NFPA codes are generally adopted by local and state governments for enforcement by electrical and building inspectors and fire marshals.

1.5.2 Health care codes and standards

Additional electrical requirements for health care facilities are included in the Accreditation Manual for Hospitals published by the Joint Commission for the Accreditation of Health Care Organizations (JCAHO). Hospitals seeking JCAHO accreditation must undergo periodic inspection by JCAHO examiners. Accreditation depends on the hospital's conformance with the requirements included in the accreditation manual.

The Department of Health and Human Services formerly published a standard entitled, *Minimum Requirements for Construction and Equipment of Hospitals and Medical Facilities* and enforced it on a national basis. The American Institute of Architects (AIA) obtained the copyright in 1987 and produced a revision called Guidelines for Construction and Equipment of Hospitals and Medical Facilities.⁴ AIA revised the document again in 1992–1993. It is still enforced by many state and federal agencies.

Electrical designers working on projects for the Department of Veterans Affairs, Department of Defense, the General Services Administration, Public Buildings Service, and other government agencies must be aware that these agencies generally publish standards for electrical design. These standards or guidelines can be obtained from the appropriate agency.

1.5.3 Local, state, and federal codes and regulations

While most municipalities, counties, and states use the NEC without change, some have their own codes. In some instances the NEC is adopted by local ordinance as part of the building code, with deviations from the NEC listed as addenda. It is important to note that only the code adopted as of a certain date is official, and that governmental bodies may delay adopting the latest code. Federal rulings may require use of the latest NEC regardless of local rulings, so that reference to the enforcing agencies for interpretation on this point may be necessary.

Some city and state codes are almost as extensive as the NEC. It is generally accepted that in the case of conflict, the more stringent or severe interpretation applies. Generally the entity responsible for enforcing the code has the power to interpret it.

⁴This publication can be obtained from AIA Press, 1735 New York Avenue, Washington, DC 20006 (tel. 800-365-2724). A 1996 edition is expected to be published shortly.

Failure to comply with NEC or local code requirements can affect the owner's ability to obtain a certificate of occupancy and may have a negative effect on insurance.

In most states, health care construction comes under the jurisdiction of a state health department. In some instances the state will have its own hospital or health care code with specific electrical requirements.

Both state and local authorities may adopt and enforce one of the model building codes written by a regional building officials group. These include the Standard Building Code, the Uniform Building Code™, and the National Building Code.

Legislation by the U.S. federal government has had the effect of giving standards, such as certain ANSI standards, the impact of law. The Occupational Safety and Health Act, administered by the U.S. Department of Labor, permits federal enforcement of codes and standards. The Occupational Safety and Health Administration (OSHA) has adopted the 1971 NEC for new electrical installations and also for major replacements, modifications, or repairs installed after 5 March 1972. A few articles and sections of the NEC have been deemed to apply retroactively by OSHA. The NFPA created the NFPA 70E Committee to prepare a consensus standard for possible use by OSHA in developing their standards. Major portions of NFPA 70E-1988 (Electrical Safety Requirements for Employee Work Places) have been included in OSHA regulations.

OSHA requirements are published in the *Federal Register*.⁵ OSHA rules for electric systems are covered in 29 CFR Part 1910 of the *Federal Register*.

The U.S. National Institute of Occupational Safety and Health (NIOSH) publishes *Electrical Alerts*⁶ to warn of unsafe practices or hazardous electrical equipment.

The U.S. Department of Energy, by encouraging building energy performance standards, has advanced energy conservation standards. A number of states have enacted energy conservation regulations. These include ASHRAE/IESNA legislation embodying various energy conservation standards such as ASHRAE/IESNA 90.1-1989, Energy Efficient Design of New Buildings Except Low-Rise Residential Buildings. These establish energy or power budgets that materially affect architectural, mechanical, and electrical designs.

1.5.4 Standards and recommended practices

A number of organizations in addition to the NFPA publish documents that affect electrical design. Adherence to these documents can be written into design specifications.

ANSI approves the standards of many other organizations. ANSI coordinates the review of proposed standards among all interested affiliated societies and organizations to ensure a consensus approval. It is in effect a clearinghouse for technical standards of all types.

⁵The *Federal Register* is available from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402 (telephone 202-783-3238) on a subscription or individual copy basis.

⁶Copies of this bulletin are available from NIOSH Publications Dissemination, 4676 Columbia Parkway, Cincinnati, OH 45226.

Underwriters Laboratories, Inc. (UL)⁷ is a non-profit organization, operating laboratories for investigation with respect to hazards affecting life and property, materials and products, especially electrical appliances and equipment. In so doing, they develop test standards. Equipment that has been tested by UL or another nationally recognized testing organizations (i.e., OSHA), and found to conform to their standards, is known as listed or labeled equipment.

The National Electrical Manufacturers Association (NEMA)⁸ represents equipment manufacturers. Their publications serve to standardize the manufacture of, and provide testing and operating standards for electrical equipment. The design engineer should be familiar with any NEMA standard that might affect the application of any equipment to be specified.

1.6 Reference books

The American Hospital Association (AHA) publishes a series of books on topics of interest to hospital engineers. The series is called the *Management and Compliance Series* (MACS). The books are available from the AHA at 840 North Lakeshore Drive, Chicago, IL 60611. Of particular interest to the electrical engineer will be Volume 4, *Fire Warning and Safety Systems* and Volume 7, *Electrical Systems for Health Care Facilities*. Other volumes deal with a wide variety of subjects, including medical gas systems and heating, ventilation, and air conditioning (HVAC) systems.

The Illuminating Engineering Society of North America (IESNA) publishes a *Lighting Handbook* in two volumes. Volume 2, *Applications*, includes a chapter on lighting for health care facilities.

The introduction to the IEEE Gray Book includes a list of additional references and handbooks that may be of interest to the health care electrical designer.

1.7 Periodicals

Spectrum, the basic monthly publication of the IEEE, covers all aspects of electrical and electronic engineering with limited material on health care facilities. This publication, however, does contain 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. The *Transactions* of the Industrial Applications Society and the Engineers in Medicine and Biology Society of the IEEE can be useful to health care electrical engineers.

Following are some other well-known periodicals:

⁷333 Pfingsten Road, Northbrook, IL 60020.

⁸2101 L Street, NW, Washington, DC 20037.

ASHRAE Journal, American Society of Heating, Refrigerating and Air-Conditioning Engineers, 1791 Tullie Circle NE, Atlanta, GA 30329.

Biomedical Engineering, 233 Spring Street, New York, NY 10013.

Consulting-Specifying Engineer, Cahners Publishing Company, 5 South Wabash Avenue, Chicago, IL 60603.

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

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

Fire Journal, National Fire Protection Association, Batterymarch Park, Quincy, MA 00269.

Health Care Systems, 1515 Broadway, New York, NY 10036.

Health Facilities Management, American Hospital Publishing, Inc., 737 N. Michigan Avenue, Suite 700, Chicago, IL 60611-2615.

Hospitals, American Hospital Publishing, Inc., 737 N. Michigan Avenue, Suite 700, Chicago, IL 60611-2615.

IAEI News, International Association of Electrical Inspectors, 901 Waterfall Way, Richardson, TX 75080-7702.

Journal of Clinical Engineering, 1351 Titan Way, Brea, CA 92621.

Journal of the Operating Room Research Institute, 100 Campus Road, Totowa, NJ 07512.

Lighting Design and Application, Illuminating Engineering Society of North America, 345 East 47th Street, New York, NY 10017.

Medical Electronics, 2994 West Liberty, Pittsburgh, PA 15216.

Modern Healthcare, 740 N. Rush St., Chicago, IL 60611.

Neta News, published by the International Electrical Testing Association, 231 Red Rocks Vista Drive, P.O. Box 687, Morrison, CO 80465.

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

Professional Engineer, National Society of Professional Engineers, 1420 King Street, Alexandria, VA 22314.

1.8 Manufacturers' data

The electrical industry through its associations and individual manufacturers of electrical equipment issues many technical bulletins, data books, and magazines. While some of this information is difficult to obtain, copies should be made available to each major design unit. The advertising sections of electrical magazines contain excellent material, usually well illustrated and presented in a clear and readable form, concerning the construction and application of equipment. Such literature may be promotional; it may present the advertiser's equipment or methods in a best light and should be carefully evaluated. Manufacturer's catalogs are a valuable source of equipment information. Some manufacturers' complete catalogs are quite extensive covering several volumes. However, these companies may issue condensed catalogs for general use. A few manufacturers publish regularly scheduled magazines containing news of new products and actual applications. Data sheets referring to specific items are almost always available from the sales offices. Some technical files may be kept in microfilm for use either by projection or by printing at larger design offices. Manufacturers' representatives, both sales and technical, can do much to provide complete information on a product.

Manufacturers of specialized hospital electrical equipment often publish design and installation recommendations and technical updates. This is particularly true of isolation panel, standby system, and transfer switch manufacturers.

1.9 Safety

Safety of life and preservation of property are two of the most important factors in the design of the electrical system. This is especially true in health care facilities because of public occupancy, thoroughfare, high-occupancy density, and patients—some of them critically ill or injured. In some health care facilities the systems operating staff has limited technical capabilities and may not have any specific electrical training.

Various codes provide rules and regulations as minimum safeguards of life and property. The electrical design engineer often needs to provide greater safeguards than outlined in the codes according to his best judgment, while also giving consideration to utilization and economics.

Electrical safety may be divided into the following five categories:

- a) Safety for maintenance and operating personnel
- b) Safety for the general public
- c) Safety for general care patients
- d) Safety for critical care patients
- e) Safety for patients and staff in wet locations

Safety for maintenance and operating personnel is achieved through proper design and selection of equipment with regard to enclosures, key-interlocking, circuit breaker and fuse interrupting capacity, the use of high-speed fault-detection and circuit-opening devices, clearances from structural members, grounding methods, disconnecting means, and identification

of equipment. Adequate lighting in electrical rooms and around electrical equipment is important to personnel safety.

Safety for the general public requires that all circuitmaking and breaking equipment as well as other electrical apparatus be isolated from casual contact. This is achieved by using locked rooms and enclosures, proper grounding, limiting of fault levels, installation of barriers and other isolation, proper clearances, adequate insulation, and other similar provisions outlined in this standard. Only authorized personnel should have access to electrical equipment.

Safety for general patients requires all of the design features used for protecting the general public as well as special provisions to minimize potential differences between any two conducting surfaces likely to come in contact with the patient directly or indirectly. Green ground conductors, installed in metallic conduit with the power conductors, ensure that potential differences are below 20 mV when first installed. Potential differences in general patient care areas are required to be maintained below 500 mV under normal conditions. Potential differences in critical care areas must be kept below 40 mV under normal conditions. However, the designer must be aware that even with properly sized and installed ground conductors, higher potential differences can be generated during fault conditions. Other special protective systems such as ground-fault circuit-interrupter (GFCI) receptacles or isolation transformers are used in wet locations to protect patients and staff and in critical care areas to protect catheterized patients from electric shock through an exposed catheter.

Although flammable anesthetics (like ether) are no longer used in the U.S., they are still popular in some foreign countries. Where flammable anesthesia is used, isolation transformers and a properly grounded conductive floor shall be provided. All wiring in the hazardous area must be installed as required for Class 1 Division 1 locations.

The National Electrical Safety Code® (NESC®) (ANSI C2-1997) is available from the IEEE. It covers outdoor distribution systems, supply and communications systems, overhead lines, high-voltage systems, and other items related to the supply of building power.

Circuit protection is a fundamental safety requirement of all electrical systems. Adequate interrupting capacities are required in services, feeders, and branch circuits. Selective, automatic isolation of faulted circuits represents good engineering. Tripping schemes for the emergency system must be selective, so that faults on adjacent branches or systems or faults on the emergency system itself do not disrupt service to unaffected emergency system circuits—especially if interruption of these circuits can jeopardize the lives or safety of patients. Physical protection of wiring by means of approved raceways under all probable conditions of exposure to electrical, chemical, and mechanical damage is necessary.

Circuits on the emergency system shall be installed in metallic raceway. Circuits to patient care areas shall be installed with a green ground conductor and should be installed in metallic raceway to ensure physical protection and to provide redundant grounding. Such raceways should be of sufficient size for future expansion. Additional raceways and spare conductors for future use may be installed within allowable financial constraints. If the raceways are properly constructed and bonded, they can minimize power interruptions. The design engineer should locate equipment where suitable ambient temperatures exist and ventilation

is available. The operation of fault-detection and circuit-interruption devices under conditions of abnormal voltage and frequency should be ensured.

1.9.1 Appliances and equipment

Improperly applied or inferior materials can cause electrical failures. The proper use of appliances and equipment listed by the Underwriters Laboratories, Inc., or other nationally recognized testing laboratories is recommended. The Association of Home Appliance Manufacturers (AHAM)⁹ and the Air-Conditioning and Refrigeration Institute (ARI)¹⁰ specify the manufacture, testing, and application of many common appliances and equipment.

High-voltage equipment should be specified to be manufactured in accordance with NEMA, ANSI, and IEEE standards, and the engineer should make sure that the equipment specified conforms to these standards. Properly prepared specifications can prevent the purchase of inferior or unsuitable equipment. The lowest initial purchase price may not result in the lowest cost after taking into consideration operating, maintenance, and owning costs. Value engineering is an organized approach to identification of unnecessary costs; it utilizes such methods as life cycles, cost analyses, and related techniques.

1.9.2 Operational considerations

When the design engineer plans electrical equipment rooms and locates electrical devices, there may be areas accessible to unqualified persons due to limited space. Dead-front construction and ANSI/NEMA Category A type construction should be utilized whenever practical. Where dead-front construction is not available, all exposed electrical equipment should be placed behind locked doors or gates. This will result in a reduction in electrical failures caused by human error, as well as improved safety.

A serious cause of failure, which is attributable to human error, is unintentional grounding or phase-to-phase short-circuiting of equipment that is being worked upon. By careful design such as proper spacing, barriers, and padlocking and by enforcement of published work-safety rules, the engineer can minimize unintentional grounding and phase-to-phase, and ground faults in the distribution equipment. High-quality workmanship is an important factor in the prevention of electrical failures. Therefore, the design should incorporate features that are conducive to good workmanship.

Selective coordination of overcurrent devices is important in health care facilities, especially for critical care areas of hospitals. The system must be studied for both high- and low-level faults. It is therefore important to consider the different levels of available short-circuit current available from utility and standby sources.

Ground-fault protection schemes on large service mains on wye-grounded 480 V systems will help to minimize damage from arcing ground faults. Arcing ground faults or “burn-

⁹20 North Wacker Drive, Chicago, IL 60606.

¹⁰1501 Wilson Boulevard, Arlington, VA 22209.

downs” can cause total destruction of electrical equipment, jeopardizing patient safety by fire and loss of electrical service. By providing one or more additional steps of ground-fault protection downstream, designers can ensure that otherwise harmless ground faults (such as in the powerhouse or kitchen) will not cause an outage of the hospital main or patient care areas of the hospital. Ground-fault systems should be tested for selective tripping to ensure proper and safe operation per the NEC.

1.10 Maintenance

Maintenance is essential to proper operation. The installation should be so designed that building personnel can perform most of the maintenance with a minimum need for specialized services. Design details should provide proper space and accessibility so that equipment can be maintained without difficulty and excessive cost.

The engineer should consider the effects of a failure in the system supplying the building. Generally, the external systems are operated and maintained by the electrical utility, though at times they are a part of the health care facility distribution system.

In health care facilities where continuity of service is essential, suitable emergency and standby equipment should be provided. Such equipment is needed to maintain minimum lighting requirements for passageways, stairways, and to supply power to critical patient care areas and essential loads. These systems are usually installed within the building, and they include automatic or manual equipment for transferring loads on loss of normal supply power or for putting battery- or generator-supplied equipment into service.

Although applicable codes determine the need for standby or emergency generating systems in health care facilities, they are generally required in any facility that keeps acutely ill patients overnight, performs invasive procedures, administers anesthesia, has critical patient care areas, or otherwise treats patients unable to care for themselves during an emergency. High-rise health care facilities, regardless of type, should have on-site emergency or standby generators. Periodic testing and exercising of standby generators is essential to system reliability.

Electrical engineers should consider the installation of bypass/isolation switches in conjunction with automatic transfer switches to permit maintenance on a deenergized transfer switch without jeopardizing patient safety. The isolation/bypass switch permits removal of the transfer switch from the circuit while providing for manual transfer to the normal or emergency source.

Even with isolation/bypass switches, it is possible for a load-side circuit breaker to fail, causing loss of power to all or part of the critical branch. For this reason it is recommended to provide some normal circuits in critical patient care areas per the NEC.

1.11 Design considerations

Electrical equipment usually occupies a relatively small percentage of the total building space, and in design it may be easier to relocate electrical service areas than mechanical areas or structural elements. Allocation of space for electrical areas is often given secondary consideration by architectural and related specialties. In the competing search for space, the electrical engineer is responsible for fulfilling the requirements for a proper electrical installation while at the same time recognizing the flexibility of electrical systems in terms of layout and placement.

Today, architectural considerations and appearances are of paramount importance in the design of a health care facility. Aesthetic considerations may play an important role in the selection of equipment, especially lighting equipment. Provided that the dictates of good practice, code requirements, and environmental considerations are not violated, the electrical engineer may have to compromise the design to accommodate the needs of other members of the design team.

The electrical engineer should work closely with professional associates, such as the architect, the mechanical engineer, the structural engineer, and the civil engineer. There is also concern with the building owner or operator who, as clients, may take an active interest in the design. More often the electrical engineer will work directly with the coordinator of overall design activities, usually the architect. Cooperation with the safety engineer, fire protection engineer, the environmental engineer, and other concerned people, such as interior designers, all of whom have a say in the ultimate design, is essential.

The electrical designer should become familiar with local rules and know the authorities having jurisdiction over the design and construction. The designer should always contact the authorities having jurisdiction and all applicable utilities before beginning design. Local contractors are usually familiar with local ordinances and union work rules and can be of great help. Union work practices may, for reasons of safety or other considerations, discourage the use of certain materials and techniques.

In performing electrical design, it is essential, at the outset, to prepare a checklist of all the design stages that have to be considered. Major items include temporary power, access to the site, and review by others. It is important to note that certain electrical work may appear in nonelectrical sections of the specifications. For example, furnishing and connecting of electric motors and controls may be covered in the mechanical section of the specifications. Another notable example would be elevators, which are usually specified by the architect. The electrical engineer should insist that the proper starter, fireman's recall system, and emergency sequencing of elevators are specified.

Electrical engineers working on health care projects should have a working knowledge of medical gas systems because medical gas outlets often share consoles and headwalls that appear in the electrical specifications. The electrical engineer also should be familiar with medical gas alarm systems.

For administrative control purposes, the electrical work may be divided into a number of contracts, some of which may be under the control of a general contractor and some of which may be awarded to electrical contractors. Among items with which the electrical designer will be concerned are preliminary cost estimates, final cost estimates, plans or drawings, specifications (which are the written presentation of the work), materials, manuals, factory inspections, laboratory tests, and temporary lighting and power. The electrical engineer may well be involved in providing information on how electrical considerations affect financial justification of the project in terms of owning and operating costs, amortization, return on investment, and related items.

1.12 Other considerations

Those involved in the design of health care facilities should understand the process by which drawings are issued for bidding and construction. The designer should also have some knowledge of shop drawing review, estimating, and contract administration. For more information see the Introduction (Chapter 1) to the IEEE Gray Book.

Design and construction of health care facilities are a team process involving engineers, architects, construction managers, general contractors, estimators, subcontractors and equipment vendors. In recent years the contractors and construction managers have become increasingly involved in the design process. In order to successfully complete a health care project, it is important to involve contractors who have a successful track record in health care construction. The larger and more complex the project the more important it is to have contractors who are skilled and experienced in the specialized construction techniques required for medical facilities.

Chapter 2

Load requirements and energy management

2.1 General discussion

As with other building types, the determination of loads to be served by the electrical system is fundamental to health care facility design. Equally important is the economic application of materials, labor, and electrical devices to serve identified loads. As a goal, the completed facility should serve the initial loads, provide a margin for incremental growth, and foster the efficient use of energy.

2.1.1 Loads

One of the purposes of this chapter is to aid the designer in estimating loads usually found in health care facilities and to show the range of power typically required by these loads.

2.1.2 Groups of loads

The cumulative effect of groups of individual loads is one of the determinants of distribution system design. This chapter will provide data from operating health care facilities that will be useful in projecting total load demand. Similarly, a profile for one type of facility will be presented. The reader is cautioned that such data should be viewed within the narrow scope in which it is presented. That is, the data is indicative of a specific building at a specific point in time and cannot be extrapolated necessarily into a typical profile.

2.1.3 Load growth

Patterns of health care have changed rapidly in recent years, and as the biological sciences continue to advance, altering patterns may be expected in the future. Such changes impose on health care facilities the need to adapt to changing demands of many kinds. The designer of electrical systems should plan for inevitable change and should anticipate incremental growth of loads during the useful life of the facility. In fact, the designer's recognition of the dynamic nature of health care facilities may result in extended useful life. Obviously, the type of health care facility affects the level of change that may be anticipated. Teaching hospitals are more prone to change than community general hospitals, and the latter more so than custodial care facilities.

2.1.4 Energy utilization

Electrical system design affects the energy required to operate a facility over its useful life. This consideration should be balanced with the loads to be served as the design is created. Another purpose of this chapter is to present data that will help reduce the unknowns faced by the designer, resulting in a more energy-efficient facility. Additionally, techniques of energy management will be discussed.

2.2 Loads vs. facility type

There are many types of health care facilities, some of which are identified in Chapter 1. Load density for the total building will vary as the type varies.

Teaching and general hospitals may be expected to offer the broadest spectrum of load types and to yield the highest concentration of load per gross square foot. Conversely, minimal care and custodial care facilities will produce generally low concentrations of load.

Outpatient screening clinics and physicians' offices will be similar to commercial office buildings, except that screening clinics sometimes will include extensive laboratory, radiology, and imaging facilities.

Psychiatric hospitals, nursing homes, and minimal care and custodial care facilities share a common bond since large portions of each will be devoted to patient accommodations. While the similarity will stop there in most cases, the load density (watts per gross square foot) will be influenced significantly by their residential character.

Load density is related to other variables in addition to facility type. As an example, choice of fuel for heating and air conditioning will exert considerable influence on loads.

2.3 Lighting loads

Lighting for health care facilities is presented in Chapter 7. Loads imposed by the lighting systems will be a function of several variables, among which are

- a) Tasks to be performed
- b) Quality and quantity of illumination required
- c) Choice of lighting sources

Lighting design for some areas will be similar to that for other commercial buildings. Other spaces will require the application of specialized lighting techniques. Among the latter are patient rooms, intensive care units, nurseries, and surgical and obstetrical suites.

In all cases, task lighting techniques should be applied, in the interest of energy management and of optimum distribution system capacity.

2.3.1 Loads by function

For initial calculations, lighting connected loads may be estimated relying on the designer's previous experience or they may be estimated using the Illuminating Engineering Society of North America (IESNA) lighting power budget technique. Readers should refer to the references and bibliography for this chapter (see 2.7 and 2.8) and to the body of Chapter 7 for more on this subject.

2.3.2 Lighting demand

As with other types of loads, demand factors may be applied to lighting connected load when determining distribution system component capacity. The appropriate factor will depend upon some or all of the following:

- a) Function performed in the area served
- b) Means of lighting control, i.e., switching, dimming
- c) Hours of operation for the area served
- d) Local code authority requirements

As an upper limit, the continuous load supplied by a lighting branch circuit should not exceed 80% of the branch circuit rating. For good design practice, the continuous load supplied should not exceed 70% of the branch circuit rating and in some cases should be even lower.

The National Electrical Code® (NEC®) (NFPA 70-1996)¹ permits the use of lighting demand factors in calculating lighting load on feeders. Refer to table 220-11 of the NEC. However, designers should develop their own factors based on the characteristics of a specific project, consistent with restraints imposed by code authorities.

The factors shown in table 2-1 may be used in sizing the distribution system components shown and should result in a conservative design.

Table 2-1 — Factors used in sizing distribution system components

Distribution system component	Lighting demand factor
Lighting panelboard bus and main overcurrent device	1.0
Lighting panelboard feeder and feeder overcurrent device	1.0
Distribution panelboard bus and main overcurrent device	
First 50 000 W or less	0.5
All over 50 000 W	0.4
Remaining components	0.4

2.4 Power loads

Power loads may be divided into the following broad categories:

- a) Building equipment
 - 1) Heating, ventilating, air conditioning, and refrigeration (HVAC&R)
 - 2) Transportation (elevators, escalators, trolleys)
 - 3) Auxiliary pumps (fire, sump, clinical air and vacuum, pneumatic tube)
- b) Functional equipment
 - 1) Kitchen
 - 2) Data processing

¹Information on references can be found in 2.7.

- 3) Communication systems
- 4) Business machines
- 5) Laundry
- c) Medical equipment
 - 1) X-ray and imaging systems
 - 2) Radiation therapy
 - 3) Laboratory
 - 4) Surgery
 - 5) Intensive care, recovery, emergency
 - 6) Physical and occupational therapy
 - 7) Inhalation therapy
 - 8) Pharmacy
 - 9) Materials management
 - 10) Medical records

NOTE—Major loads occur in the first two categories [a) and b)], and these loads are similar to those in other types of commercial buildings. The third category [c)] is unique to health care.

2.4.1 Building equipment

The types of HVAC&R systems chosen for a specific building will have the greatest single effect on electrical load. First, the choice of fuel will be critical. If natural gas, fuel oil, or coal is chosen, electrical loads will be lower than would be the case if electricity were chosen. Second, the choice of refrigeration cycle will have considerable impact. If absorption chillers are chosen, electrical loads will be lower than those imposed by electric centrifugal or reciprocating chillers. Early discussions between mechanical and electrical designers will be advantageous in planning the electrical distribution system.

For initial estimates, before actual loads are known, the factors shown in table 2-2 may be used to establish the major elements of the electrical system serving HVAC&R systems.

Elevators usually are large loads, but since only a few are required in most health care facilities, elevators do not represent a large portion of total load. For preliminary design of the distribution system in buildings of up to 12 stories, assuming vertical speeds up to 450 ft/min, 4500 lb capacity, the following loads may be used:

Electric traction elevators, each	35–50 hp
Hydraulic elevators, each	40–75 hp

Hydraulic elevators ordinarily will not be employed in buildings higher than seven stories and speeds usually will be limited to 150 ft/min. However, capacities may be higher than 4500 lb. Actual loads should be obtained from the elevator vendor once vertical transportation requirements have been defined sufficiently to permit calculation.

Escalators are not installed frequently in health care facilities but may be employed in a few buildings. For initial estimates, escalator load will approximate 25 hp for each landing served above the first.

**Table 2-2—Factors used to establish major elements
of the electrical system serving HVAC&R systems**

Item	Unit
Refrigeration machines:	kVA/ton of chiller capacity
Absorption	0.10
Centrifugal/reciprocating	1.00
Auxiliary pumps and fans:	
Chilled water pumps	0.08
Condenser water pumps	
Absorption	0.15
Centrifugal/reciprocating	0.07
Cooling tower fans	
Absorption	0.10
Centrifugal/reciprocating	0.07
Boilers:	kVA/boiler hp
Natural gas/fuel oil	0.07
Boiler auxiliary pumps:	kVA/boiler hp
Deaerator	0.10
Auxiliary equipment:	kVA/bed
Clinical vacuum pumps	0.18
Clinical air compressors	0.10

Horizontal and vertical transportation systems for food, supplies, and materials using automated trolleys or carts are found in a few large health care facilities. Pneumatic tube systems are more common and may be employed as the sole means of transport for small supplies and paper records or as one component in a materials handling system. Automated trolleys or carts impose relatively small loads (less than 10 hp) at numerous locations but will usually be combined with dedicated elevators whose loads will be similar to a service elevator. Pneumatic tube systems are powered by vacuum pumps or exhausters located in a few central locations. Motor drives will vary depending on the extent of the system but are under 10 hp (many, less than 3 hp).

2.4.2 Functional equipment

Equipment of this type usually consists of numerous small loads except that used in kitchens and except for some office copiers. The effect on the electrical system is to require panel-board space and multiple branch circuits but low load density.

The choice of fuel in the kitchen is the major determinant. If natural gas is the primary fuel, electrical loads will be lower on a watts per square foot basis than where electricity is the primary fuel. Preliminary planning should address this question early. For estimating purposes, the following factors may be used. In calculating kitchen floor area include cooking and preparation, dishwashing, storage, walk-in refrigerator/freezer, food serving lines, tray assembly, and offices.

<u>Primary fuel</u>	<u>W/ft²</u>
Natural gas	25
Electricity	125

Data processing equipment is employed in several areas of the typical hospital. As a minimum, stand-alone systems for patient and general accounting and for laboratory analyses may be anticipated. However, it is common to find these integrated into hospital-wide management information systems today. Such systems use multiple input stations throughout the hospital, all intended to produce a unified patient bill at the time of patient discharge plus inventory control, third party billing, and portions of the patient's medical record.

As in other types of facilities, computer power requirements are usually moderate at the central processor location and low at distributed input stations. For most installations found in hospitals, the total load at the central location will range between 50 kVA and 100 kVA. Data processing facilities in large complexes, especially those associated with university medical schools, may require several hundred kilovoltampere capacity.

At computer workstations or teletype input stations, power demand will not exceed 1 kVA.

Power demand from communication systems, as individual loads and as a whole, is low. Individual loads will not exceed 2 kVA usually, with most less than 1.5 kVA.

As in other commercial structures, there will be a large quantity of office equipment (typewriters, word processors, copiers) but power required will be low, on the order of 0.3–1.2 kVA per item. The exception will be large copy machines. These may be estimated at 3–6 kVA each.

2.4.3 Medical equipment

Types of medical equipment employed in the various departments of health care facilities are discussed in Chapter 9.

Power distribution systems serving multiple x-ray machine installations require special attention. Designers should always be guided by the specific data furnished by vendors supplying equipment for the specific facility. However, an excellent planning guide is available as a NEMA standard (NEMA XR9-1984) and should be consulted.

Quality of voltage supplied is important to x-ray installations. Again, service as direct as possible from the source is desirable. Minimum transient disturbance and voltage drop are essential.

Note that most x-ray machines have two load ratings—continuous and momentary. The continuous load is usually small and poses little problem for either source—utility or standby generator. The momentary demand, however, can be a problem for a standby generator, especially a large x-ray machine served by a small generator. Since x-ray machines have a high power factor, a real power load is imposed on the engine. The effect of this should be evaluated in sizing the engine-generator set.

While momentary demand of x-ray installations will figure prominently in feeder and distribution equipment sizing, it need not be considered in calculating overall power demand imposed on the utility source, provided it is a part of a moderate size system. If the system

requires 750 kVA or more, the momentary nature of x-ray operation will not add measurably to the overall demand. For small systems and for additions to existing facilities where service equipment is near capacity, some provision for x-ray demand may be advisable.

Clinical laboratories in hospitals require numerous branch circuits to serve the multitude of electrical devices, but load density is usually low and individual equipment loads are low, most under 1 kVA. A few pieces of equipment in laboratories today perform multiple specialized tests. The loads for these will range between 3 kVA and 8 kVA each. These same items often are sensitive to transient conditions on the power system and may require locally applied surge arrestors.

2.5 Overall demand factors

A tabulation of actual service entrance demand per gross square foot is presented in tables 2-3 and 2-4 for a group of health care facilities. Data used in preparation of these tables was obtained from the Veteran's Administration, now the Department of Veterans Affairs, and the Hospital Corporation of America. Refer to footnotes accompanying the tables for the criteria on which these tables are based. This data was collected during 1977 and 1981.

Table 2-3—Service entrance peak demand (Department of Veterans Affairs)

Hospital	Floor area (ft ²)	Beds ^a	Degree days ^b		Principal ^c fuel	W/ft ² ^d	
			Cooling	Heating		Maximum	Average
V.A. Hospital #1	821 000	922	234	3536	NG/FO	4.5	3.5
V.A. Hospital #2	334 000	500	863	5713	NG/FO	5.2	3.9
V.A. Hospital #3	645 995	670	3488	1488	NG/FO	3.8	2.8
V.A. Hospital #4	681 000	600	1016	654	NG/FO	6.1	4.0
V.A. Hospital #5	503 500	697	3495	841	NG/FO	7.2	5.5
V.A. Hospital #6	800 000	1050	600	7400	NG/FO	5.9	4.2

^aTotal beds shown. Beds actually occupied could affect values shown for watts per square foot.

^bDegree days: Normals, Base 65 °F, based on 1941–1970 period. From *Local Climatological Data Series*, 1974, NOAA.

^cNG/FO = Natural Gas/Fuel Oil. Principal fuel is defined as that used for heating. In all cases, electricity was the fuel used for refrigeration.

^dWatts per square foot based on measured values at service entrance during metering periods ranging from 9 days to 17 days, during cooling season in all instances, 1981.

**Table 2-4—Service entrance peak demand
(Hospital Corporation of America)**

Hospital and location	Floor area (ft ²)	Beds ^a	Degree days ^b		Principal ^c fuel	W/ft ² ^d Maximum
			Cooling	Heating		
#1 – East	273 000	458	1353	3939	NG/FO	6.8
#2 – Southeast	278 000	250	2294	2240	NG/FO	6.3
#3 – Central	123 000	157	—	—	NG/FO	7.5
#4 – Central	36 365	62	2029	3227 ^e	E	13.7
#5 – Central	318 000	300	1107	4306	NG/FO	4.6
#6 – Southeast	182 000	225	3786	299 ^e	NG/FO	5.3
#7 – East	283 523	320	1030	4307	NG/FO	6.8
#8 – Southwest	135 396	150	2250	2621 ^e	NG/FO	6.6
#9 – West	190 000	97	927	5983	NG/FO	2.8
#10 – Southeast	161 000	170	3226	733 ^e	NG/FO	6.3
#11 – Southeast	157 639	214	2078	2146	NG/FO	7.3
#12 – Southeast	162 187	222	2143	2378 ^e	NG/FO	4.3
#13 – East	109 617	146	1030	4307 ^e	NG/FO	5.7
#14 – East	76 000	153	1030	4307 ^e	E	8.8
#15 – Southeast	135 150	190	1995	2547 ^e	NG/FO	5.9
#16 – Southwest	75 769	131	2587	2382 ^e	NG/FO	7.4
#17 – Central	75 769	128	1636	3505 ^e	NG/FO	6.3
#18 – Northwest	129 000	150	714	5833 ^e	NG/FO	4.4
#19 – Central	54 938	108	1694	3696 ^e	E	13.3
#20 – West	144 000	160	2814	1752	NG/FO	4.5
#21 – Southeast	149 000	123	2078	2146 ^e	NG/FO	4.5
#22 – Central	89 000	128	2029	3227 ^e	E	8.4
#23 – Central	128 500	150	1197	4729 ^e	NG/FO	6.2
#24 – West	135 169	170	927	5983 ^e	NG/FO	4.7
#25 – Southeast	80 000	124	1722	2975 ^e	NG/FO	6.2
#26 – Southeast	83 117	126	3226	733 ^e	NG/FO	8.5
#27 – Central	51 000	97	1569	3478	E	8.8
#28 – Southeast	66 528	120	2929	902 ^e	E	9.7
#29 – East	112 000	140	1394	3514	NG/FO	4.3
#30 – Central	202 000	223	1636	3505	NG/FO	4.8
#31 – Southeast	56 000	51	3786	299 ^e	NG/FO	7.4
#32 – West	47 434	50	927	5983 ^e	NG/E	7.0
#33 – Central	23 835	32	1694	3696 ^e	E	10.8
#34 – Southeast	105 000	95	2706	1465 ^e	NG/FO	8.3
#35 – West	48 575	60	3042	108 ^e	NG/E	7.7

**Table 2-4—Service entrance peak demand
(Hospital Corporation of America) (Continued)**

Hospital and location	Floor area (ft ²)	Beds ^a	Degree days ^b		Principal ^c fuel	W/ft ² ^d Maximum
			Cooling	Heating		
#36 – Southwest	133 000	185	2587	2382 ^e	NG/FO	6.3
#37 – Central	42 879	66	1694	3696 ^e	E	15.7

^aTotal beds shown. Beds actually occupied could affect values shown for watts per square foot.

^bDegree days: Normals, Base 65 °F, based on 1941–1970 period. From *Local Climatological Data Series*, 1974, NOAA.

^cNG/FO = Natural Gas/Fuel Oil; E = Electricity. Principal fuel is defined as that used for heating. In all cases, electricity was the fuel used for refrigeration.

^dWatts per square foot based on measured values by utility company meter at service entrance, 1977.

^eData shown for nearest recorded location.

(Each facility was self-contained, in that refrigeration and air conditioning equipment loads are included in power demands shown.)

The tables show the type of facility, the gross floor area and number of beds for each, the geographic location, and the major fuel type employed for HVAC&R systems in that facility. The derived factors may be used to estimate the anticipated demand for other facilities similar in size, location, and type of fuel. They also may be used to make initial estimates of service entrance capacity, switchgear size, and space required for service entrance equipment. It is important to recognize, however, that they will be useful principally in the schematic design phase. As design proceeds through the preliminary and working drawing phases, these initial estimates should be modified by the actual conditions prevalent in the project.

Figures 2-1 and 2-2 present operating load data for a large general medical and surgical hospital located in the southeastern U.S. It should be useful in visualizing changes in demand over time for a typical operating hospital. Candler General Hospital is a 305-bed facility, 402 000 gross ft², situated in Savannah, Georgia. The principal fuel employed for heating is natural gas with fuel oil standby. The chillers are centrifugal. Staff obtained the data during the cooling season, the peak period in this location.

2.6 Energy management

To gain a better perspective of the impact of energy management on the nation's plan to meet future energy goals, an overall view of past, current, and projected energy usage is necessary. Government and independent researchers have developed energy consumption projections to the year 2000 based on historical data on the total domestic energy usage over the past 81 years. Figure 2-3 is a graphic representation of usage from 1900 to 1981. Energy used in "quads" is plotted against years. A quad is one quadrillion Btu (2.93×10^{11} kWh), or more conveniently stated, the approximate amount of energy used by a city of one million people every three years. The distribution of usage by industrial, residential and commercial, and transportation is respectively three-eighths, three-eighths, and one-quarter of the total: 74 quads. An extrapolation of the historical data and a reasonable projection by the National Academy of Sciences to the year 2000 indicates consumption could be 175 quads. By incor-

porating the best estimates of the impact of “energy conservation” by the Department of Energy (DOE) and other government and private agencies, the 175 quad projection could be reduced by 65 quads to 110 quads, still 36 quads more per year than used in 1981. Since the current level of usage is better than 15% beyond domestic production capabilities, including nuclear and renewable sources, the truth about the “energy crisis” is apparent.

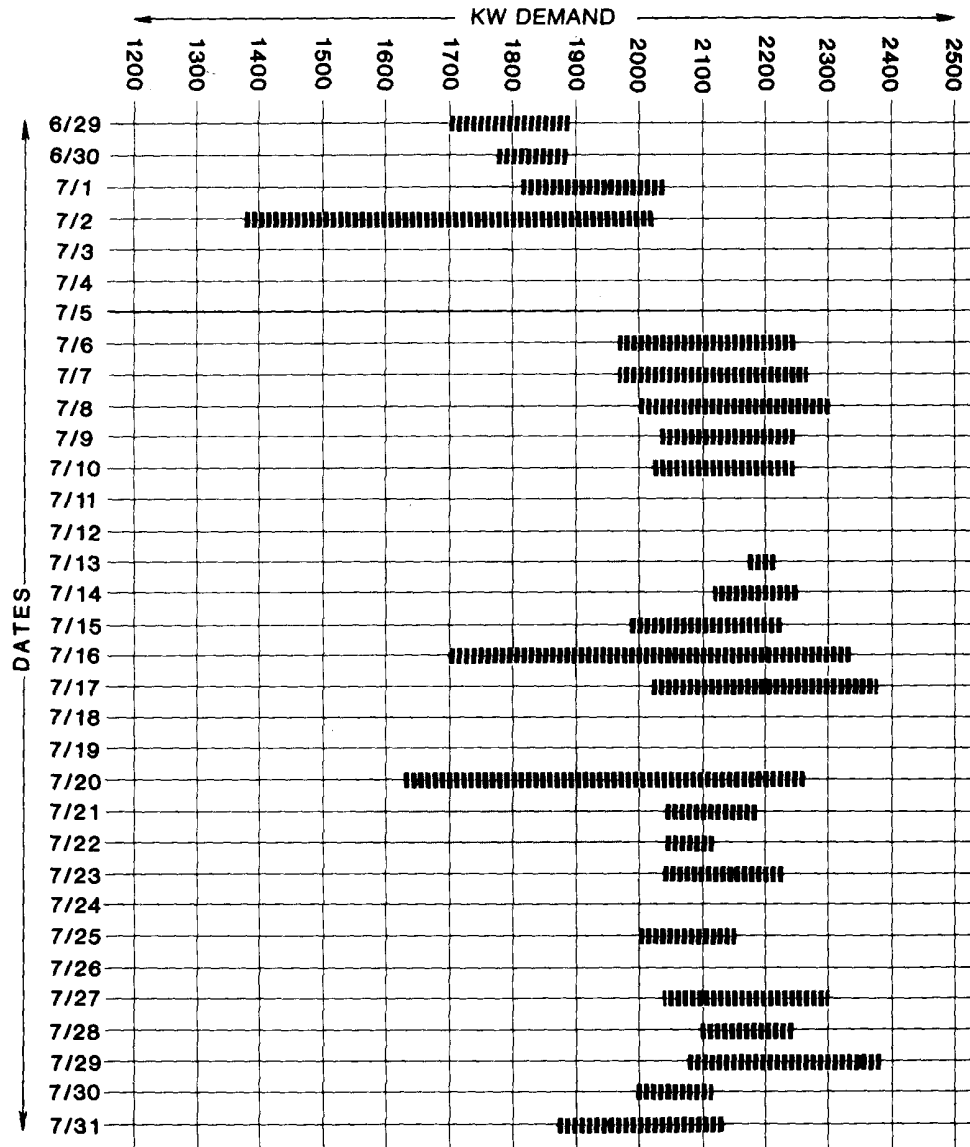


Figure 2-1 — Load profile—Candler General Hospital
6/29/81–7/31/81 kilowatt demand

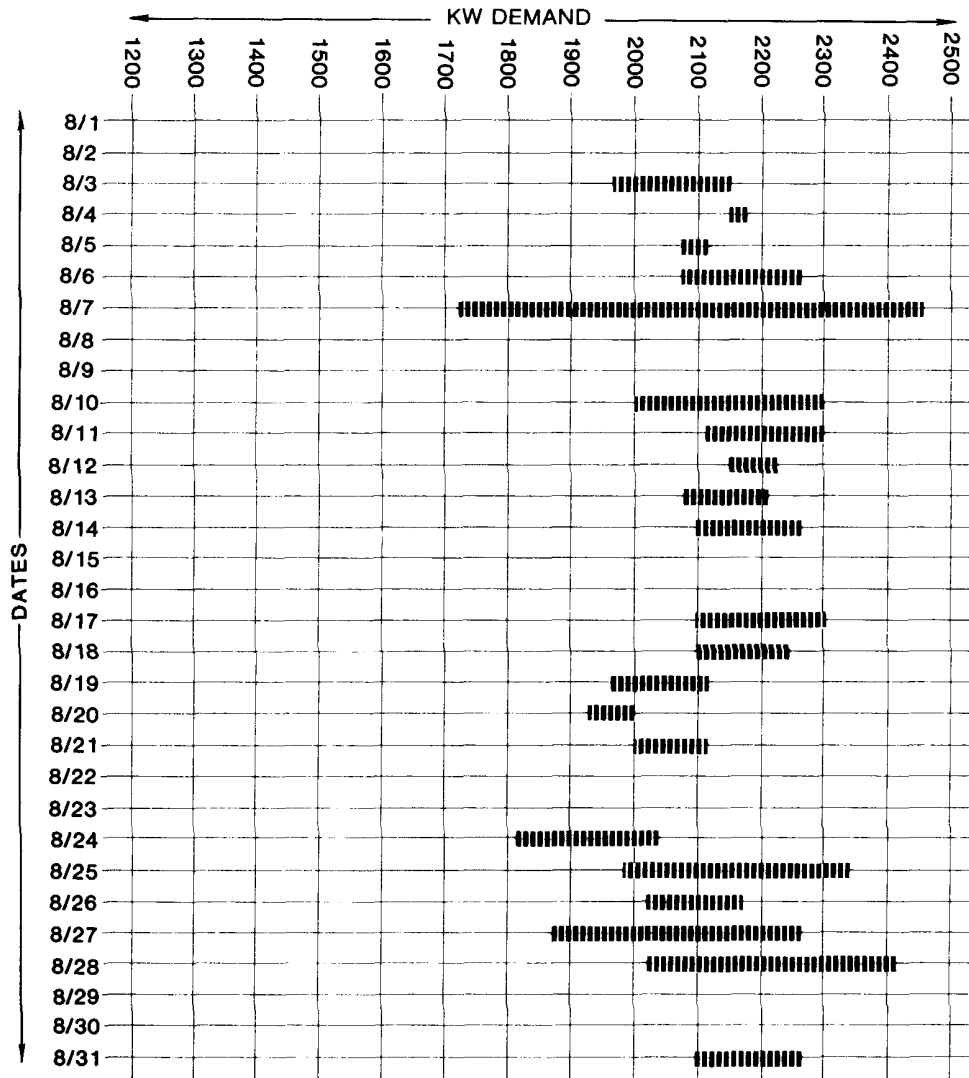


Figure 2-2—Load profile—Candler General Hospital
8/1/82–8/31/82 kilowatt demand

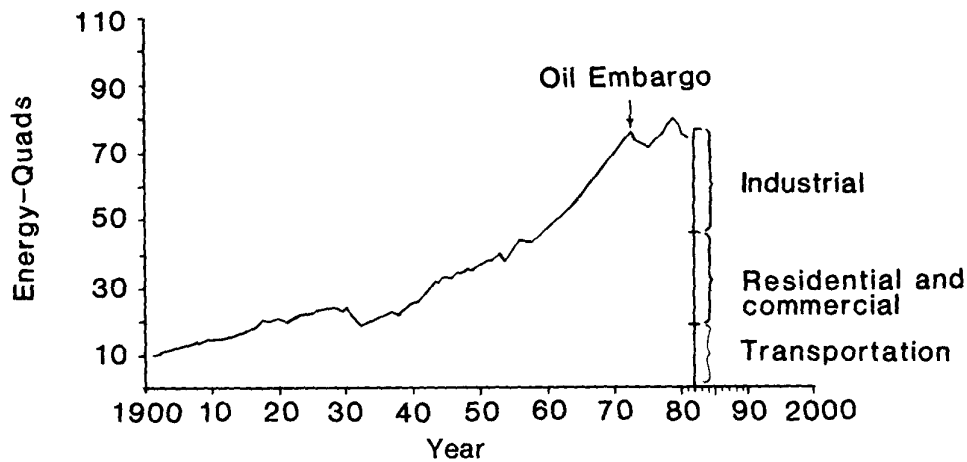


Figure 2-3—U.S. energy consumption

Energy consumption in buildings totaled about 26 quads in 1981, which includes residential and commercial sectors. Total energy consumption of hospitals was 1.1 quads. Assuming fixed percentages for estimating to the year 2000, 2.4 quads will be required without energy conservation measures and 1.5 quads with conservation, a reduction of approximately one-third.

Energy management implies implementation of energy conservation measures and control strategies over operating systems to minimize energy consumed. The designer has a responsibility to examine alternative design approaches and present these to the building owner with their respective cost considerations. This arises not only from the need to conserve fuels but also to control health care costs.

To develop an energy management program for any building, it is necessary to first know its energy using systems and the fuels to most effectively serve them.

The energy input to a hospital can arrive in a number of forms: electricity, natural gas, fuel oil, purchased steam, coal, or other fuels. The size of the stream depends on the rate of fuel consumption and the British thermal units of energy in that fuel. Oil and natural gas, of which the nation faces a limited supply, are important energy inputs in many hospitals. Even when they are not consumed directly, these nonrenewable fossil fuels may have been used to produce other fuels. The total of all energy streams to a hospital is utilized for a number of functions. While the pattern in an individual hospital may vary, the largest single energy usage is usually the heating, ventilation, air conditioning, and refrigeration (HVAC&R) system. Lighting represents the second most important use of energy in hospitals. Since the beginning of efforts to conserve energy, there have been a number of attempts to establish Building Energy Performance Standards. Today, enough data has been accumulated to assist a designer in understanding what constitutes an efficient building. The American Hospital Association with its energy management program is an example.

Energy usage in hospitals usually consists of electric power and a source for heating and process steam needs, such as gas, oil, or more electricity. Table 2-5 shows the typical energy usage for a general, acute care hospital in a moderate climate. The large difference in HVAC&R motor energy usage results from electric chiller energy in the cooling season.

Table 2-5—Typical energy usage

Cooling season	Btu/h/ft ²	%
Lighting	6.8	17
Receptacles	3.4	8
Medical, kitchen equipment	1.8	4
HVAC&R motors	12.0	29
Domestic hot water	8.0	19
Sterilization steam	4.0	11
Miscellaneous	<u>5.0</u>	<u>12</u>
TOTAL	41.0	100

Heating season	Btu/h/ft ²	%
Lights	6.8	10
Receptacles	3.4	5
Medical kitchen equipment	1.8	3
HVAC&R motors	5.0	7
Domestic hot water	8.0	12
Sterilization steam	4.0	6
Heating	<u>40.0</u>	<u>57</u>
TOTAL	69.0	100

2.6.1 Energy economics

Energy codes promulgated since 1975 impose some mandatory requirements for energy conservation and suggest other voluntary opportunities that could be implemented. Incumbent on the building designer is the responsibility to investigate not only the energy conservation opportunities suggested, but also to evaluate nonrenewable fuel sources, energy recovery systems, operating system monitoring and controls, and maintenance management. Beyond the mandated requirements, most owners will require substantiation of the cost effectiveness of implementing energy conservation measures (ECMs).

Several methods exist for determining the cost effectiveness of alternative system designs. Common to all are two basic cost elements: (1) the cost to implement, or first cost, and (2) the net cost savings provided. Two of the methods are simple payback and life cycle costing.

- a) *Simple payback.* The simplest method is the payback period. This method for determining the cost effectiveness of added ECMs is calculated by applying the following formula:

$$\text{Payback Period} = \frac{\text{First Cost}}{\text{Annual Savings} - \text{Annual Costs}}$$

The payback period is expressed in years. Annual savings are the first year's savings in energy. Annual costs are the increased maintenance costs due to the measure. First cost is the total installed cost of the improvement.

Generally ignored in this method of analysis are the following:

- 1) Cost of money—the annual interest on money borrowed
- 2) Replacement cost—the cost to replace equipment
- 3) Energy cost inflation—the cost of energy in future years
- 4) Tax saving—the savings on purchase of equipment generated by federal tax incentives
- 5) Depreciation

Where the payback period is three years or less, this method is usually accurate enough to facilitate a decision.

- b) *Life cycle costing.* Life cycle costing is a means of evaluating the total cost of owning, operating, and maintaining a building or piece of equipment over its useful life. This method involves a systematic comparison of the estimated costs using a discount factor to relate future to present value.

The procedures required to prepare a life cycle cost analysis are

- 1) Establish nonfuel cost data, both initial investment and recurring cost
- 2) Establish energy cost data for the time period chosen
- 3) Determine life cycle costs
- 4) Determine net savings
- 5) Calculate savings-to-investment ratio
- 6) Perform certain sensitivity analyses
- 7) Measure cost effectiveness

2.6.2 Utility negotiations

In most cases, the selection of a power source will be determined by an analysis made by the design engineers and the utility engineers. With the exception of large high-load factor complexes, economics will dictate the purchase of electricity for prime power requirements. On-site total energy and cogeneration systems should be evaluated on a case-by-case basis considering fuel availability, environmental restrictions, and utility costs. Standby electric generating equipment will be provided in hospitals to produce emergency power for critical loads upon failure of the prime source and may be used to reduce peak demand on the utility source.

The designer of hospital power systems has an important role in selection of the distribution characteristic within the complex, the power source, and subsequently, upon the long-term power costs. To make cost-effective decisions for owners, the designer should have knowledge of utility rate structures, metering, and billing practices.

- a) *Electric utility tariffs.* Each electric utility has a series of rate schedules for supplying power to customers under various conditions. To arrive at the most economic choice for obtaining power, a comparison of these rates should be made. The following are factors that usually form the basis for establishing rates and evaluating them:
- 1) Maximum demand in kilowatts or kilovoltamperes
 - 2) Energy consumption in kilowatthours
 - 3) Adjustment for low power-factor
 - 4) Voltages available
 - 5) Transformer or substation ownership
 - 6) Utility fuel cost adjustments
 - 7) Demand interval
 - 8) Minimum bill stipulations, including ratchet clauses
 - 9) Multiple-metering provisions
 - 10) Auxiliary or standby service charges
 - 11) Seasonal and time-of-day service rates
 - 12) Prompt payment savings
 - 13) Provisions for off-peak loads and interruptible loads
 - 14) Load factor

Since the oil embargo of 1973, and as a direct consequence of the National Energy Act of 1978, electric utilities introduced “rate reform.” Essentially, rate reform usually incorporates various forms of

- Inverted rates
- Flat rates
- Lifeline rates
- Marginal cost pricing
- Long-range incremental costing
- Construction work in progress
- Interruptible rates
- Time-of-day pricing
- Reduction in the number of declining blocks
- Modifications of utility fuel cost adjustments
- Deletion of electric discounts

- b) *Utility metering.* An understanding of utility metering practices is important for evaluating service arrangements. Practices vary depending upon local utility and regulatory body requirements. The design, usage, and load characteristic for a given application should be carefully weighed before selecting service voltage and metering characteristics. If large momentary demand, highly seasonal, or low power-factor loads are involved, billing penalties may be involved. On the other hand, high load-factor or high power-factor loads may merit a billing allowance or credit.

It is good practice to contact the electric utility supplying service early in the design. Late utility negotiations may result in increased costs and delays in service. A complete discussion of service, metering, and billing is always in order, no matter how preliminary. This should provide time for the consideration of various proposals and the selection of the one best suited to a given application. See [B2]² for more information.

- 1) *Metering by type of premises.* Availability of a particular kind of metering and billing often depends upon the type of building and load. A single-occupancy building, such as a hospital, usually will be metered by the utility at the service entrance with a watthour demand meter. Should multiple services be required, and should they be permitted by the electric utility, watthour demand meter reading sometimes may be totalized to take advantage of lower rates.

In some medical facilities, it may be desirable to submeter portions of the buildings. This could arise where physician offices, separately-owned pharmacies, or other concessionaires lease space within the project. Consent of the utility company should be obtained in such instances.

- 2) *Metering by service-voltage characteristics.* Metering of the incoming service may be located on the high-voltage or low-voltage side of the transformer, depending on the terms of the contract with the electric utility. When the meter is on the primary side, the transformer losses will be charged to the customer. In some cases, the customer is given a discount to offset this loss. When metering is on the secondary side, utilities may add 1–2% to the bill for transformer losses or may install a device to increase the meter indication to account for transformer losses.
- 3) *Meter location.* Subject to agreement with the utility, the meter may be installed indoors at the customer's secondary distribution point, in a suitable meter room, or in a separate control building that may also house primary switchgear and associated controls.

Outdoor installations include pole, exterior wall, and pad mounting. In general, utilities will require accessibility for meter readings and maintenance, and suitable meter protection.

- 4) *Types of metering.* Tabulated below are types of metering. Utility requirements govern the types available for a given project.
 - i) Master metering
 - ii) Multiple metering
 - iii) Primary metering
 - iv) Secondary metering
 - v) Totalized metering
 - vi) Impulse metering
 - vii) Compensated metering
 - viii) Submetering
 - ix) Subtractive metering

²The numbers in brackets correspond to those of the bibliography in 2.8.

- x) Coincident demand
 - xi) Telemetry
 - xii) Power factor metering
 - xiii) Kilovoltampere metering
- c) *Utility billing.* It is customary for utilities to meter and bill each customer individually. Utility rates consider fixed and variable cost requirements to provide services. Hence “rate schedules” generally take the form of a “block” rate, wherein incremental costs usually vary as a function of customer usage. Electric costs generally comprise two components—the demand charge and the energy charge. The demand charge is based upon the maximum rate of energy usage. The energy charge is based upon the total energy consumption. Many utilities have been granted permission to add variable cost factors to their rates. Examples include purchased fuel differential and real estate tax differential costs. Under these provisions, the utility may pass along increased costs; however, the utility must pass along decreased costs as well.

For hospital complexes, the primary metering and attendant billing forms are the following:

- 1) *Conjunctural billing.* Large institutional customers within the territory served by a given utility should explore the availability of conjunctural billing. This consists of adding the readings of two or more meters for purposes of a single billing. Due to the usual practice of decreasing rates for larger consumption, conjunctural billing may result in a lower energy usage billing than individual meters would produce. Conjunctural billing will generally result in a higher demand charge than a master or totalizing meter because the maximum demand readings on the individual meters are added. Since maximum demands seldom occur simultaneously, the arithmetic sum will be greater than the simultaneous sum, unless a provision is made for coincident demand measurement.
- 2) *Power factor billing.* If the load to be served will result in a low power-factor, an evaluation should be made to determine if power-factor improvements can be justified to avoid penalties.
- 3) *Flat billing.* Some applications involve service to loads of a fixed characteristic. For such loads, the utility may offer no-meter or flat-rate service. Billing is based upon time and load characteristics. Examples include area lighting and remote pumping stations.
- 4) *Off-peak billing.* This is reduced rate billing for service utilized during off-peak periods such as water-heating loads. The utility monitors, and may control, off-peak usage through control equipment or special metering.
- 5) *Standby service billing.* Also known as breakdown or auxiliary service, this service is applicable to utility customers whose electric requirements are not supplied entirely by the utility. In such cases, billing demand is determined either as a fixed percentage of the connected load or by meter, whichever is higher. This applies to loads that are electrically connected to some other source of supply but for which breakdown or auxiliary service is required.

- 6) *Backup service billing.* This service is provided through more than one utility circuit, solely for a customer's convenience. The customer often bears the cost of establishing the additional circuit and associated facilities. Usually, each backup service is metered and billed separately.
- 7) *Demand billing.* Usually this represents a significant part of electric service billing, and a good understanding of kilowatt demand metering and billing is important. An electric demand meter measures the rate of use of electric energy over a given period of time, usually 15 min, 30 min, or 1 h time intervals. The demand register is manually reset periodically when read for billing purposes.
- 8) *Minimum billing demand.* A utility customer may be subject to minimum demand billing, generally consisting of (a) a fixed amount or (b) a fixed percentage of the maximum demand established over a prior billing period. This type of charge may apply to customers with high instantaneous demands, customers whose operations are seasonal, or those who have contracted for a specific service capacity. Equipment and service requirements should be reviewed carefully to reduce or avoid minimum billing demand charges.

Utility contracts also may include ratchet clauses that establish minimum demand charges based on maximum demand experienced in the previous contract period (e.g., one year's peak demand establishes next year's minimum demand). Designers should advise their clients to control peak demand for several reasons but especially where the utility contract includes a ratchet clause. Clients should be aware that a major decrease in demand may not be reflected in savings for up to 12 months, unless a modification to the ratchet clause is negotiated.

- 9) *Load factor billing.* The ratio of average kilowatt demand to peak kilowatt demand during a given time period is referred to as the load factor. Many utilities offer a billing allowance or credit for high load factor usage, a qualification usually determined by evaluating how many hours during the billing period the metered peak demand was used. As an example of such credit, the utility may provide a reduced rate for the number of kilowatthours that are in excess of the peak demand multiplied by a given number of hours (after 360 h for a 720 h month or a 50% load factor).
- 10) *Interruptible service.* A form of peak load shaving used by the utilities is interruptible service. Primarily available for large facilities with well defined loads that can be readily disconnected, the utility offers the customer a billing credit for being able to require a reduction of demand to a specified contract level during a curtailment period. If the customer fails to reduce actual demand during any curtailment period, at least to the contract demand, severe financial penalties are imposed.

2.6.3 Conservation measures

Table 2-5 shows that methods to conserve lighting and HVAC&R energy can have a noticeable impact on a hospital's energy expenditures and, therefore, its operating budget.

- a) *Lighting retrofits are a proven method of energy reduction.* Replacing standard wattage fluorescent lamps with energy-saving lamps reduces energy costs with very little reduction in lumen output. Regular maintenance of luminaires, lamps, and ballasts is essential to energy efficiency regardless of types employed. For even greater savings, it is recommended that incandescent luminaires be replaced with fluorescent or high-intensity discharge (HID) luminaires and that high-efficiency ballasts be specified in all cases.
- b) *On-site cogeneration.* On-site cogeneration is the simultaneous production of electric power at the point of use along with the production and use of the heat energy by-product of the electrical generation process. Its economic attraction is that the practice may be more efficient than utility-produced power. The national average for system efficiency of utility-produced power is 30%, whereas on-site cogeneration under ideal conditions can achieve a system efficiency of 80%.

Most cogeneration systems installed in hospitals and other institutional buildings are reciprocating engines (gas or diesel) and gas turbines. The exhaust gases from the engines are passed through a waste heat boiler and can produce 125 psig steam. In addition, the jacket water and lube oil cooling systems of a reciprocating engine can be used to heat hot water. Reciprocating engines have the highest ratio of electrical to thermal energy output and often are the best choice to match the electrical and thermal base loads of a hospital. Ebulliently-cooled reciprocating engines (those in which low pressure steam is produced in the jacket cooling system) can be used where only low-pressure steam (15 psig) or hot water is required (they cannot, however, provide 125 psig steam to laundries or 80 psig steam to sterilizers).

Gas turbines are sometimes applicable, although usually a larger thermal base load, such as a laundry or absorption chillers, is necessary to make them economically attractive. Steam turbines are rarely seen in hospital applications since most hospital boiler systems do not produce the high-pressure steam (300 psig and above) required to justify their costs.

The selection of type and size of equipment depends on many variables, e.g., electrical demand, steam quantities and pressures desired, occupancy and load patterns, and electric rate structure. An accurate study should be performed to determine feasibility at a particular hospital site.

Installed costs for engine generators and waste heat recovery systems run approximately \$700/kW to \$1200/kW.

- c) *Peak demand shaving.* Rather than an alternative method of generating one's own power, this is a technique that lowers the monthly demand charge by controlling or scheduling loads so as not to exceed a pre-set limit. Programmable demand controllers can shed loads automatically, to reduce the peak demand. Generating power from a standby power system is an alternative.

The many arguments, pro and con, for using the existing emergency generators boil down to a single question: will the local building authorities allow it? If not, one may employ conventional load shedding only. If so, an analysis of loads that may be dropped (administrative office areas, medical offices, etc.) will give enough information to estimate a simple payback. Further, it may be possible to use the same standby emergency generators as required by codes, without adding additional generators.

- d) *Thermal storage.* The idea of using cheaper, “off-peak” energy at night for use during “on-peak” daytime hours is becoming more economically feasible, especially as electric utilities increase the demand charge in their rate structure. By making chilled water or ice at night, then melting it during the day, the large electric demand of the water chillers is shifted to the less expensive night time.

Three methods for thermal storage consist of ice storage, eutectic salt systems, and chilled water systems. Ice storage systems produce ice in a tank and then use the building’s chilled water system to melt the ice. These systems require the least storage space but require a glycol additive to the circulating water and more energy-intensive low-temperature chillers. Eutectic salt systems utilize a salt solution in sealed containers that freeze at 45–50 °F; thus conventional chillers may be used, but since the latent heat of fusion of the salt solution is less than that of pure water, more storage space is required for the salt containers. Chilled water storage is the simplest system but requires much more storage space.

Installed costs for these systems range from \$80/ton-h to \$200/ton-h.

- e) *Building envelope.* Replacement of clear, single-pane windows with tinted, double-pane insulating glass reduces building heating and cooling requirements, and therefore, energy costs. Weather-stripping and regular building maintenance help to reduce outside air infiltration and its resultant heating/cooling costs.

2.6.4 Design considerations

Energy conservation and capital cost are frequently in conflict with one another. An energy management program should optimize this relationship. Achieving a balance requires consideration of the following topics during design.

- a) *Energy value of materials.* Construction materials and equipment possess energy value, built in from mine to construction site. Energy value is added during erection and installation.

Recognition of this helps the designer to avoid over-design. Careful analysis of initial loads to be imposed coupled with allowances for load growth are essential. At the same time, efficient materials and equipment may increase capital costs while lowering operating costs.

- b) *Lighting and lighting control.* As noted earlier in this chapter, lighting source choices and lighting control bear directly on energy utilization as well as system load. Principles of task lighting, general lighting, and daylighting are important design considerations for energy management.
- c) *Motors.* Selection of motors for efficient use of energy is essential. The use of premium energy-efficient motors can reduce running losses by 25% or more. Induction motors are somewhat less efficient at partial load, but their power factors are considerably poorer. Motors should be chosen to operate at three-quarters load or more. The use of solid-state starters to reduce starting current and the use of variable-speed drives for optimum control of motor loads contribute to energy conservation.

- d) *Power factor maintenance.* Prediction of system power factor is difficult during design but more readily determinable in an operating system. Nonetheless, consideration should be given to application of capacitors at three-phase, constant-speed induction motors. In addition, application of power factor correction capacitors or synchronous condensers to the system should be evaluated during design and provisions should be made to install them without major renovations of switchgear. Where nonlinear loads are present, care should be taken when adding capacitors to avoid resonance.

2.6.5 Energy management systems

Use of an energy management system (EMS) is an accepted and frequently recommended way to lower energy and demand costs and to conserve energy. Energy management is a technique for automatically controlling the demand and energy consumption of a facility to a lower and more economical level by implementing operating strategies that optimize system performance to meet building needs more efficiently.

Coordination among owner, architect, and engineers during schematic design may enable use of an EMS for fire and security systems, communication systems, and maintenance management.

An EMS may be simple or complex in design and capability. Controls such as time clocks constitute a simple EMS where an on or off command is given to an item of equipment at predetermined times. Often these simple devices miss the more focused and expanded needs of the energy and maintenance managers. Computerized systems can replace much of the lost time expended by maintenance crews to verify operating status of boilers, fans, and other equipment. It can enable control of HVAC&R functions and lighting from a central unit, performing operations such as start/stop, load shedding, and controlling air mixtures. These functions can be accomplished using mid-range energy controllers.

For maximum energy and manpower saving, the state-of-the-art utilizes direct digital control (DDC) systems. Previous systems had all of the programmable intelligence in the central processing unit (CPU). The remote panels were slaves implementing CPU instructions. They had no stand-alone intelligence. A CPU failure would mean total system shutdown and loss of control and critical data. Today's systems have minicomputers and microprocessors spread throughout the system, including field controllers. The main computer is free to perform sophisticated energy management tasks, while simpler tasks are delegated to the field controller. Each controller can be a stand-alone management center reporting to the central system, and if the main CPU or a transmission link fails, the entire system is not disabled.

Options available today include color graphics on computer workstations, routine operator input/output, conversational English communication, file editing and print-outs, and fire and security functions.

- a) Systems for a large building, such as a hospital, should include the following:
 - 1) Time program control
 - 2) Optimum start/stop

- 3) Supply air and water supervisory control
 - 4) Boiler/chiller plant optimization
 - 5) Enthalpy control
 - 6) Load shedding/demand limiting
 - 7) Variable duty cycling
 - 8) Supervisory feedback
- b) It should be possible to add features such as
- 1) Use of light pens for system operation
 - 2) Higher power computers
 - 3) End-user programming
 - 4) Fiber optics transmission

An important consideration in any system is the means by which communication among various pieces of equipment is accomplished. Options include hardwiring, telephone lines, wireless, and carrier current. This is particularly important if the EMS is being designed for application in an existing facility.

Issues that must be faced when starting system design include answers to such questions as how much control does the owner want the system to have over electrical HVAC&R systems? Should the control be distributed to the satellite field panels throughout the project? If the system is to control the emergency power generation, how extensive should the backup be and should the fail-safe switchover be manual or automatic? What is the smallest item to be monitored or controlled by the system?

Refer to NEMA MG10-1983 for techniques to evaluate starting and stopping cycles of electric motors. Some energy management system manufacturers claim no appreciable change in equipment life due to energy management systems. It is advisable that the designer study the technical literature for conclusions of future studies on this subject.

Finally, a critically important consideration in selecting EMS equipment is the service available from the manufacturer for diagnosis and repair of hardware, for modification of system and operating software, and for training of the owner's personnel in utilizing the system.

2.6.6 Energy utilization standards

A uniform standard for energy utilization in various types of facilities does not exist. Several nationally recognized building codes, the 1993 BOCA® National Energy Conservation Code for example, mandate performance for some building components. A number of states have written and adopted energy codes. The Department of Energy is continuing to develop Building Energy Performance Standards (BEPS). Designers may refer to ASHRAE/IESNA 90.1-1989 and ASHRAE/IEEE 90A-1-1988 for general guidance in conserving energy. The IESNA also published a series on Lighting Energy Management (IES LEM-1-1982, IES LEM-2-1984, IES LEM-3-1987, and IES LEM-4-1984) with recommendations for power and energy densities in buildings. However, since 1995, only LEM-3-1987 remains as an active publication. The IEEE Bronze Book (IEEE Std 739-1995) includes recommendations for energy management and conservation.

Other work toward standards has been done by the National Institute for Building Sciences; the American Institute of Architects Research Corporation; the American Society of Heating, Refrigeration and Air Conditioning Engineers; and the American Hospital Association.

In the meantime, designers are obliged to consult legally adopted codes in the jurisdiction where the facility will be constructed and to strive for the lowest energy consumption consistent with the building owner's life-cycle-cost goals.

2.7 References

This chapter shall be used in conjunction with the following publications:

ASHRAE/IEEE 90A-1-1988, Energy Conservation in New Building Design (Sections 1–9).³

ASHRAE/IESNA 90.1-1989, Energy Efficient Design of New Buildings Except Low-Rise Residential Buildings.

BOCA® National Energy Conservation Code, 7th ed., 1993.⁴

IEEE Std 739-1995, IEEE Recommended Practice for Energy Management in Industrial and Commercial Facilities (IEEE Bronze Book) (ANSI).⁵

IES LEM-3-1987, Design Considerations for Effective Building Lighting Energy Utilization.⁶

NEMA MG 10-1983 (Revised 1988), Energy Management Guidelines for Selection and Use of Polyphase Motors.⁷

NEMA XR9-1984 (R 1989), Power Supply Guidelines for X-Ray Machines.

NFPA 70-1996, National Electrical Code® (NEC®).⁸

NFPA 99-1996, Health Care Facilities.

³ASHRAE publications are available from the Customer Service Dept., American Society of Heating, Refrigerating, and Air Conditioning Engineers, 1791 Tullie Circle NE, Atlanta, GA 30329.

⁴The BOCA® National Energy Conservation Code is available from the Building Officials and Code Administrators (BOCA) International, Inc., 4051 West Flossmoor Road, Country Club Hills, IL 60478-5795, tel. (708) 799-2300.

⁵IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331.

⁶IES publications are available from the Illuminating Engineering Society of North America, 120 Wall Street, Fl 17, New York, NY 10005-4001.

⁷NEMA publications are available from the National Electrical Manufacturers Association, 1300 N. 17th St., Ste. 1847, Rosslyn, VA 22209.

⁸NFPA publications are available from Publications Sales, National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101.

2.8 Bibliography

Additional information may be found in the following sources:

[B1] Crook, E. D., *Determination of Electrical Demand for V.A. Medical Buildings*. Washington, DC: Veteran's Administration, Office of Construction, 1982.

[B2] Edison Electric Institute, *Handbook of Electricity Metering*, 9th ed.

[B3] Harold, R. M., et. al. *Lighting Power Budget Determination by the Unit Power Density Procedure*, Illuminating Engineering Society (IES), Publication No. EMS-6, 1979.

Chapter 3

Electrical power distribution systems

3.1 General discussion

As the medical profession is increasingly more dependent upon complex electrical equipment and instrumentation for patient care and facility operation, the proper design of electrical power distribution systems in health care facilities is most important. The proper selection of the system components, and their arrangement, is critical to providing the health care facility with reliable, safe, and economical electric power.

Total or partial loss of electric power in a health care facility can cause acute operational problems (i.e., power loss to the lighting systems makes it impossible to perform vital medical tasks such as dispensing medicine, performing surgical procedures, or performing precise medical laboratory work). The loss of power to tissue, bone, or blood bank refrigerators can leave the health care facility without these vital resources. Power loss to electrical life support equipment such as heart pumps, medical vacuum pumps, dialysis machines, and ventilators can be fatal. Clearly, continuity of high-quality electric power should be the most important factor in the design of the electrical distribution systems for health care facilities.

Safety is another particularly important design criteria for health care facilities because

- a) Medical personnel frequently come into contact with electrical apparatus in their daily routines.
- b) Patients often are very vulnerable to electrical shock hazard because of their weakened condition, because of drugs or anesthesia administered, and/or because of their unconscious state. Electrical shocks that would not severely affect a healthy person could be fatal to a patient.
- c) It is necessary for maintenance personnel in health care facilities to come in daily or weekly contact with electrical distribution equipment for routine maintenance or minor system additions and renovations.

Maintainability, expandability, and flexibility are also very important design criteria. The designed system shall allow needed preventive and failure maintenance to be done with little disruption to the operations of the hospital. New technologies are always being presented to the medical profession. These new technologies may require additional power, additional support systems, and often new building areas. The ability to expand, and the flexibility to change, the distribution system to meet these new technologies are also very important design criteria.

Another design criteria is economy. Public and political pressure is always present to reduce the cost of health care and to develop a more competitive market place for health care. Therefore, facility designs, including electrical distribution system designs, should consider economics. The designer shall consider both the initial cost and the operating expense of the electrical system.

This chapter will develop these basic design criteria as they relate to system planning, electrical power systems, voltage considerations, current considerations, grounding, overcurrent protection and coordination, electrical equipment, and installation and system arrangements.

3.2 Systems planning

Basic overall systems planning is the first, and probably one of the most important, phases in the overall design of an electrical power distribution system for a health care facility. During this phase, preliminary design data is gathered from administrators and staff of the health care facility, the local utility, and authorities having jurisdiction over electrical construction. All relevant national, state, and local codes, and facility design guidelines, should be reviewed. Two national codes having a major affect on health care power distribution design are

- The National Electrical Code® (NEC®) (NFPA 70-1996)¹
- NFPA 99-1996, Health Care Facilities

In addition, the architectural plans and existing site conditions should be examined from an electrical system perspective to determine potential problems and needs. The following subclauses will discuss some of the issues that should be addressed during the system planning phase of the design.

3.2.1 Consult with the project architect

A vital step in systems planning is early and ongoing coordination with the project architect. A first step is giving input to, and providing review of, the preliminary floor plan and schematics from an electrical design perspective. The architect needs the electrical designer's input as early as possible in order to avoid potential problems due to building limitations and electrical requirements such as

- a) Inadequate electrical and communication equipment room sizes
- b) Inadequate space in other certain areas having significant electrical equipment such as radiology suites or computer rooms
- c) Electrical rooms that have poor accessibility to the electrical equipment and devices, or that restrict or prohibit easy equipment removals and installations after initial construction is complete
- d) "Wet areas" that are located near or above electrical or communication rooms, which could be potentially hazardous
- e) Telephone/communications/data room size and location requirements, which do not provide needed working or maintenance clearances
- f) Ventilation, cooling, and/or exhaust needs of electrical/communication rooms, which is not provided, or is inadequate

¹Information on references can be found in 3.10.

- g) Space for needed raceways, busways, and trays that is not provided
- h) Space for the temporary installations and use of large electrical testing apparatus that is not present

It is a good practice to have all electrical equipment in rooms dedicated to such equipment. Piping, ductwork, or any architectural appurtenances that do not serve that room or space (and only those rooms) are not permitted to penetrate the walls of electrical spaces (with minor exceptions). Accordingly, the designer should work closely with the architect and mechanical engineer to ensure proper placement and utilization of electrical spaces. A problem often seen is the location of toilet rooms or mechanical equipment rooms directly over electrical spaces. Those room placements often force the installation of “forbidden” equipment in the electrical rooms.

3.2.2 Consult with the health care facility administrators, nursing and medical staff, and maintenance/operation staff, and other personnel as required

The following consultations provide information on the specific needs, requirements, constraints, and limitations of the planned facility:

- a) *The facility function.* The designer must know the specific functions to be performed in the facility. This information is needed in order to apply the proper Codes and to weigh the importance of reliability, quality of electrical power, safety, and economy. For example, the reliability designed into a distribution system serving a hospital that specializes in open heart surgery would not be justified in an outpatient clinic. Also, a facility that extensively utilizes computerized diagnostic, patient records, and accounting systems would require a higher quality of electric power than a hospital that does not use such computerized equipment. The system designer is the one charged with determining the functions of the facility.
- b) *Financial and budget information.* The designer must know the financial expectations of the administrators before beginning to develop an electrical system. The administrators typically have a fixed budget (in dollars) or have a “variable” budget (in dollars per square foot of facility). This budget must be considered in all phases of design in order to assure satisfaction. Such economic constraints, however, do not allow critical needs to be ignored simply to meet a budget. If the budget is unrealistic, the designer shall call this to the attention of the hospital administrator as soon as possible.

The administrators are concerned not only at the one-time capital costs of the projects, but also at the yearly operating costs of the installed systems. The designer should provide information on the relative operating expenses of different possible design options. The administration may decide it is better to increase the capital outlay to reduce the facility’s ongoing expenses.

- c) *Preferences on systems or equipment.* The maintenance/operational staff often have preferences on the types of systems or equipment to be installed in their building(s). The reasons for these preferences are many and varied. Whatever the reason, the designer should keep these preferences in mind throughout the system design. If the