NOT MEASUREMENT
SENSITIVE

MIL-HDBK-411B
15 MAY 1990

SUPERSEDING
MIL-HDBK-411A
21 MAY 1971

MILITARY HANDBOOK

POWER AND THE ENVIRONMENT

FOR

SENSITIVE DoD ELECTRONIC EQUIPMENT

(GENERAL)

VOLUME I

ASMC N/A

AREA SLHC

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited.

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1. SCOPE

1.1 Purpose. This three-volume handbook is a reference for the planning and engineering of power and environmental control systems for fixed Department of Defense (DoD) communications, data processing, and information systems facilities. The engineering concepts contained herein should be selectively applied to the power and environmental elements of DoD fixed facilities. DoD communications and data processing installations include equipment rooms and spaces needing more precisely controlled environments than comfort spaces. The more limiting parameters within these rooms and spaces are established specifically for the equipment being used. Outside these specially designed areas, where PCs and other electronic office equipment are used, the environment is the responsibility of the user. Power protection or conditioning for this equipment should follow the guidance provided in volume II. Environmental control of this space should follow the guidance contained in volume III. Volume I addresses these subjects in general terms for the planner, manager, or executive. Volume II addresses power system engineering considerations. Volume III addresses environmental control system engineering considerations.

1.2 Applicability. This handbook applies to and discusses the following topics:

a. Mission requirements.

b. Power requirements and characteristics.

c. Power disturbances and distribution.

d. Power conversion, conditioning, and regulation.

e. Power system monitoring and control.

f. Construction design considerations.

g. Environmental considerations.

h. Auxiliary and alternate power systems.

i. Electromagnetic interference/electromagnetic compatibility (EMI/EMC).

j. Special considerations for computer-based equipment.

1.3 Application guidance. This handbook is intended to assist in selecting and planning power and environmental control systems to be installed or upgraded at DoD communications-electronics facilities and computer-based facilities. It is applicable to the engineering effort during initial establishment of a facility or during upgrade of an existing facility. This handbook introduces practices and procedures that should be considered during the engineering design effort. This guidance does not direct that any of these control systems be employed at any given facility. Further, this guidance is not to be used solely as justification for retrofit of existing DoD communications, data processing, and information systems facilities.

1.4 Safety.

1.4.1 Safe work place. Occupational Safety and Health Administration (OSHA) regulations require a safe work place at all times. Although OSHA does not approve specific tools or products, there are Federal specifications for safet tools and they are listed in the appropriate qualified products lists (QPLs). OSHA regulations state that employees shall not be required to work in surroundings or under working conditions which are unsanitary, hazardous, or dangerous to their health and safety. Employers are required to initiate and maintain programs which comply with this requirement. These programs include inspections of job sites, materials, and equipment. They also ascertain that the use and operation of equipment or machinery is by qualified employees.

1.4.2 Confined spaces. The National Institute for Occupational Safety and Health (NIOSH) estimates that millions of workers may be exposed to hazards in confined spaces each year. Investigation of confined-space injuries and fatalities indicate that workers generally do not realize they are working in a confined space with unforeseen hazards. The studies show that testing and monitoring of the atmosphere are often not performed, and rescue procedures are seldom planned.

NIOSH’s definition of a confined space is “a space which by design has limited openings for entry and exit; unfavorable natural ventilation which could contain or produce dangerous air contaminants, and which is not intended for continuous employee occupancy.”

1.4.3 Electrical/electronic equipment. Safety procedures should be established for electronic equipment employing high voltages or radiating high-energy fields. Safety requirements have been established in individual military department documents that should be reviewed prior to designing systems in accordance with guidance contained herein.

Remember the four rules:

a. Ground everything that can accidentally become energized.

b. Keep electricity separate from equipment not to be electrified.

c. Keep heat and sparks from electrical conductors and equipment, thereby preventing a fire or triggering an explosion.

d. Do not assume safety - Electrical equipment is dangerous until proven safe.

Personnel safety concerns are expressed throughout this handbook in paragraphs that are risk-specific, such as: hazardous gas control, electromagnetic radiation safety, and equipment grounding.

2. REFERENCED DOCUMENTS

2.1 Government documents.

2.1.1 Standards and handbooks. The following standards and handbooks form a part of this handbook to the extent specified herein. Unless otherwise specified, the issues of these documents are those listed in the issue of the Department of Defense Index of Specifications and Standards (DoDISS) and supplement thereto cited in the solicitation.

STANDARDS

FEDERAL

FED-STD-1037	Glossary of Telecommunication Terms
FIPS PUB 94	Guidelines on Electrical Power for ADP Installations

(Copies of Federal Information Processing Standards (FIPS) are available to Department of Defense activities from the Standardization Documents Order Desk, Bldg. 4D, 700 Robbins Avenue, Philadelphia, PA 15111-5094. Others must request copies of FIPS from the National Technical Information Service, 5285 Port Royal Road, Springfield , VA 22161-2171.)

MILITARY

MIL-STD-188-124A	Grounding, Bonding, and Shielding for Long Haul/Tactical Communication Systems Including Ground Based Communications - Electronics Facilities and Equipments
MIL-STD-188-125	High Altitude-Electromagnetic Pulse Protection for Ground-Based Facilities Performing Time-Urgent Missions
MIL-STD-454	Standard General Requirements for Electronic Equipment
MIL-STD-461	Electromagnetic Emission and Susceptibility Requirements for the Control Electromagnetic Interference
	Electromagnetic Interference Characteristics, Measurement
	Standard Safety Program Requirements
	Human Engineering Design Criteria for Military Systems, Equipment and Facilities

HANDBOOKS

MILITARY

MIL-HDBK-232	Red/Black Engineering and Installation Criteria
MIL-HDBK-412	Site Survey and Facility Decision Handbook for Satellite Earth Stations
MIL-HDBK-413	Design Handbook for High-Frequency Radio Systems
MIL-HDBK-415	Design Handbook for Fiber-Optic Communications Systems
MIL-HDBK-416	Design Handbook for Line-of-Sight Microwave Communications
MIL-HDBK-419	Grounding, Bonding, and Shielding
MIL-HDBK-420	Site Survey Handbook for Communications Facilities
MIL-HDBK-423	High-Altitude Electromagetic Pulse Protection for Fixed and Transportable Ground-Base Facilites
MIL-HDBK-1004/3	Switchgear and Relaying
MIL-HDBK-1012/1	Electronic Facilities Engineering

(Unless otherwise indicated, copies of Federal and mi1itary standards and handbooks are available from the Standardization Documents Order Desk, Bldg. 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.)

2.1.2 Other Government documents, drawings, and publications. The following other Government documents, drawings, and publications form a part of this handbook to the extent specified herein.

(As a result of the cancellation of DoD 4630.7-M, Construction Criteria Manual, no DoD-level document on construction criteria is currently available. Individual military departments are developing construction criterial documents. Appropriate publications distribution centers should be contacted to determine availability of applicable documentation.)

MILITARY MANUALS

(Navy) NAVFAC DM-1.03	Architectural Acoustics, Functional Requirements,Design,Technology
(Navy) NAVFAC DM-3.14	Power Plant Acoustics

(Navy) NAVFAC DM-3.1	THERMAL STORAGE SYSTEMS
(Navy) NAVFAC DM-3.6	Central Heating Plants
(Navy) NAVFAC DM-4.1	Preliminary Design Consideration
(Navy) NAVFAC DM-5.7	Water Supply Systems

NOTE: Selected NAVFAC DMs are being redesignated as military handbooks. The DoDISS should be reviewed for current titles.

(Unless otherwise indicated, copies of Navy publications are available from the Standardization Documents Order Desk, Bldg. 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.)

(Army) TM 5-785 (Navy) NAVFAC P-89 (Air Force) AFM 88-29	Engineering Weather Data
(Army) TM 5-805-4 (Navy) NAVFAC DM-3.10 (Air Force) AFM 88-37	Noise and Vibration Control For Mechanical Equipment
(ARMY) TM 5-815-2 (Air Force) AFM 88-36	Energy Monitoring and Control Systems (EMCS)

(Unless otherwise indicated, military department publications are available through the specific department publications distribution center.)

2.2 Non-Government publications. The following documents form a part of this handbook to the extent specified herein. Unless otherwise specified, the issues of the documents which are DoD adopted are those listed in the issue of the DoDISS cited in the solicitation.
the issues of documents not listed in the DoDISS are the issues of the documents cited in the solicitation.

ASHRAE HANDBOOK	Fundamentals
ASHRAE HANDBOOK	Equipment
ASHRAE HANDBOOK	HVAC Systems and Applications
ASHRAE GRP 158	Cooling and Heating Load Calculation Manual

(Application for copies should be addressed to the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, 1791 Tullie Circle NE, Atlanta, GA 30329.)

ANSI-C2	National Electrical Safety Code
ANSI/IEEE STD 142	Recommended Practice for Grounding of Industrial and Commercial Power Systems
ANSI/IEEE STD 241	IEEE Reconwnended Practice for Electric Power Systems in Commercial Buildings
ANSI/IEEE STD 446	Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Application
ANSI/IEEE STD 587	IEEE Guide for Surge Voltages in Low Voltage AC Power Circuits
ANSI/NEMA MG-1	Motors and Generators
ANSI/NEMA MG-2	Safety Standard for Construction and Guide for Selection, Installation, and Use of Electric Motors and Generators

(Application for copies should be addressed to the American National Standards Institute, Inc., 1430 Broadway, New York, NY 10018.)

IEEE STD 242	IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems

(Application for copies should be addressed to the Institute of Electrical and Electronics Engineers Service Center, 445 Hoes Lane, Piscataway, NJ 08854.)

IES RR-85	IES Lighting Ready Reference

(Application for copies should be addressed to the Illuminating Engineering Society of North America, 345 E. 47th Street, New York, NY 10017.)

NFPA-30	Flammable and Combustible Liquids Code
NFPA-37	Stationary Combustion Engines and Gas Turbines
NFPA-70	National Electrical Code

(Application for copies should be addressed to the National Fire Protection Association, Batterymarch Park, Quincy, MA 02269.)

2.3 Order of precedence. In the event of a conflict between the text of this handbook and the references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained. In the event of a conflict between this handbook and another military handbook, the more specific handbook shall normally take precedence.
satellite earth station, the military handbook on that subject (MIL-HDBK-4121) would take precedence. Similarly, a conflict concerning grounding, bonding, and shielding procedures would be resolved in favor of the handbook that deals specifically with that subject; in this case, MIL-HDBK-419.

3. DEFINITIONS

3.1 Acronyms and abbreviations. The following acronyms and abbreviations used in this handbook are defined as follows:

ANSI - American National Standards Institute

ASHRAE - American Society of Heating, Refrigerating and Air Conditioning Engineers

BIL - Basic insulation level

Btu - British thermal unit(s)

CISPR - International Special Committee on Radio Interference

cfm - Cubic feet per minute

CU - Coefficient of utilization

DBT - Dry-bulb temperature

dba - Level of the A-scale of noise measurement

DDC - Direct digital control

EPA - Environmental Protection Agency

ESD - Electrostatic discharge

FIPS - Federal Information Processing Standards

GBS - Grounding, bonding, and shielding

GFCI - Ground-fault circuit interrupter

HID - High-intensity discharge

HVAC - Heating, ventilating, and air conditioning

IAQ - Indoor air quality

IC - Interrupting capacity

IEEE Institute of Electrical and Electronics Engineers

IES - Illuminating Engineering Society

LLF - Light loss factor

LPG - Liquified petroleum gas

MCC - Motor control center

NEC - National Electrical Code

NEMA - National Electrical Manufacturers Association

NFPA - National Fire Protection Association

NIOSH -National Institute of Occupational Safety and Health

OSHA - Occupational Safety and Health Administration

PF - Power factor

RH - Relative humidity

THD - Total harmonic distortion

UL - Underwriters Laboratories

VAV - Variable air volume

VCCI - Voluntary Control Council for Interference

VCP - Visual comfort probability

WBT - Wet-bulb temperature

3.2 Terms and definitions. For definitions of the terms used in this handbook, refer to Federal Standard 1u37A (Glossary of Telecommunication Terms), except as listed below, which are uniquely defined for the purpose of this handbook.

Absorption. Absorption is the process of extracting one or more substances from a fluid (air or liquid) by the holding action of a special material called an absorbent.

Adsorption. Adsorption is the process of extracting one or more substances from a fluid by the adherence of those substances to the surface of a special material called an adsorbent.

Air cleanliness. This term refers to the amount of filterable particulate material in the atmosphere air.

Air quality. Air quality is the chemical composition of the atmospheric air.

Arrester. An arrester is a protective device used as a bypass to ground for transients resulting from such things as lightning or E14P that are coupled to an antenna or other conductor. An arrester is capable of reducing the voltage and current of a transient applied to it and restoring itself to the original condition.

Balance. This term refers to regulating the flow of air or liquid in distributionnetworks

British thermal unit (Btu). British Thermal unit (Btu) is the amount of heat that must be added to or subtracted from one pound of water at 60°F to produce a temperature increase or decrease of 1°F.

Candela (cd). Candela is the basic unit of luminous intensity derived from a blackbody radiator operating at a prescribed pressure and temperature.

Clean room. Clean room is a space in which temperature, humidity, air cleanliness, air quality, air movement, air pressure, noise, and vibration are precisely controlled. The activities permitted within a clean room are also controlled. Clean rooms are often classified according to the maximum concentration of particules allowed per unit volume of air. Special electrostatic grounding systems and other transient protection may also be provided.

Coefficient of utilization (CU). Coefficient of utilization (CU) is the fractional portion of the initial lamp lumens (direct or reflected) that reaches the work surface.

Cogeneration. Cogeneration is the simultaneous generation and use of electrical power and heat energy from a single fuel source.

Coil. Coil is a cooling or heating element made of tubing or piping that is typically formed in a helical shape, either with or without fins.

Compressor. Compressor is a device that increases the pressure of gas by mechanical means.

Condenser. A condenser is a device, usually made up of pipes or tubing, that liquifies a vapor when heat is extracted.

Conditioned air. Conditioned air is indoor atmospheric air whose temperature, humidity, air cleanliness, and air quality are regulated.

Conditioned space. Conditioned space is a room or space that is provided with conditioned air.

Conductance. Conductance is the amount of heat a standard section of nonhomogeneous material will transmit under given temperature conditions.

Conduction. Conduction is a mode of heat transfer which occurs when bodies or materials with different temperatures come in contact.

Conductivity. Conductivity is the amount of heat a unit section of nonhomogeneous material will transmit under given temperature conditions.

Controller. A controller is a device that monitors a parameter and initiates a signal to a controlled device to take some corrective action when deviations from a set point are observed.

Controlled device. A controlled device is a device that starts some corrective action when a signal from a controller is received.

Convention. Convection is a mode of heat transfer in which a fluid (air or liquid) is used to transport heat. The fluid is first heated by conduction. Its higher temperature causes it to expand and move, because of lighter density. The motion creates currents which move the heated fluid to areas of lower temperature.

Cooling coil. Cooling coil is a coil which cools surrounding fluid (air or liquid) by heat exchanger action. The coil acts as either an evaporator for refrigerant or a channel for chilled water circulation.

Cooling load. This term refers to the maximum amount of heat that a cooling system will be required to remove.

Cooling tower. A cooling tower is a structure in which water is circulated and cooled by conduction and evaporation into the air.

Daylighting. Daylighting is the application of natural luminance in the form of top lighting, sidelighting, or combinations thereof, to provide a portion or all of the light in a structure.

Degree day. A degree day is the number of degrees of variation of the mean outdoor temperature from a base temperature of 65°F (18.3 °C) over 24 hours.

Design conditions. Design conditions are the high and low temperature values and related conditions, specified as limits, used to calculate heating and cooling loads. For the DoD, they are listed in the triservice manual, Engineering Weather Data (AFM 88-29, NAVFAC P-89, and TM 5-785).

Direct digital control. Direct digital control is the automated monitoring and control of the Indoor environment of a building or space, using computer-based devices.

Dry-bulb temperature. Dry-bulb temperature is the temperature of the air measured by an ordinary thermometer.

Dry-type transformer. Dry-type transformer is a transformer which is cooled by the natural or forced circulation of air, as opposed to a liquid.

Ductwork. Ductwork is a system or network of ducts used for the distribution or exhaust of air, or used to distribute power and communications conductors or cables throughout a facility.

Economizer. Economizer is an operating cycle in which cool outside air is used for cooling and the load placed on mechanical cooling is reduced.

Efficacy. This term is used to describe luminous efficiency expressed in lumens per watt.

Enthalpy. Enthalpy is the sum of sensible and latent heat in a substance. Usually concerned with moist air. Also called total heat.

Environmental control. This term refers to the conditioning of indoor atmospheric environment, involving the monitoring and control of temperature, humidity, air quality, air cleanliness, and air circulation.

Evaporation. Evaporation is the process in which a liquid changes to a vapor (gas).

Evaporator. An evaporator is the heat exchanger, used commonly in refrigeration systems,in which the refrigerant absorbs heat during evaporation.

Exitance. See luminous exitance.

Fault current. Fault current is the current that may flow in a circuit as a result of specified abnormal conditions.

Fenestration. Fenestration is any area of an outside wall of a building, such as a window, that allows light to pass.

Ground-fault circuit interrupter. A ground-fault circuit interrupter is a device to protect personnel by de-energizing a circuit or part of a circuit, within an established period of time, when the current to ground exceeds a set value which is less than the supply protection value.

Grounded conductor. A grounded conductor is a conductor in a power distribution system (usually designated the neutral) which is intentionally earth grounded, either solidly or through a grounding device.The outer jacket of the conductor, if insulated, is white in color.

Grounding conductor. A grounding conductor is a conductor which carries no current under normal conditions. It serves to connect exposed metal surfaces to an earth ground to prevent hazards in case of breakdown between current carrying parts of a power distribution system and the exposed surfaces. The outer jacket of the conductor, if insulated, is green in color, with or without a yellow stripe.

Head. This term refers to a unit of fluid pressure, usually expressed in feet. In typical usage, a given pressure is defined by the height of a column of water it will support.

Heat. Heat is energy in a substance associated with the random motion of its atoms or molecules or from radiation striking the substance. The temperature of the substance is a measure of this energy (see also latent heat, radiant heat, and sensible heat).

Heat exchanger. A heat exchanger is a device that transfers heat between two physically separated fluids.

Heat gain. Heat gain is the heat which enters a building or space through the ceiling, floor, and walls, or which is generated by personnel or equipment in the building or space.

Heat loss. This term refers to the heat loss through the ceiling, walls, and floor of a building or space.

Heat pump. A heat pump is a device which uses a thermodynamic cycle to supply heat to or remove heat from a controlled space.

Heat transfer. Heat transfer is the movement of heat by conduction, convection, or radiation.

Heating load. This term refers to the highest demand for heat that the heating system of a building will be required to supply.

Humidistat. A humidistat is a device which monitors and controls indoor

Humidity. Humidity is the amount of water vapor present in atmospheric air.

Intrinsically safe. This term refers to the incapability of devices to release sufficient energy to cause ignition of a specific atmospheric mixture under normal or specified abnormal conditions.

Joule. Joule is the energy required to transport one coulomb (metric unit of electrical charge equal to the amount of electricity transferred by a current of one ampere in one second) between two points having a potential difference of one volt.

Ltent heat. Latent heat is heat resulting from a change of state (solid, liquid, or gas) of a substance.

Load shedding. Load shedding is the capability of an electrical distribution system to remove noncritical loads during power shortages.

Lumen. Lumen is the unit of luminous flux. The luminous flux emitted within a unit solid angle by a point source having a uniform intensity of one candela.

Luminaire., Luminaire is a complete lighting unit consisting of lamp or lamps with parts to distribute the light, connect the lamps to a power source, and protect the lamps from damage.

Nanojoule. A nanojoule is one-billionth of a joule.

One-line power diagram. One-line power diagram is a diagram which, by means of single lines and graphic symbols, shows the layout of an electrical circuit and the components used therein.

Phon. Phon is a subjective unit which has a nonlinear scale and is used to quantify the loudness of sounds, using a 1000-Hertz (Hz) tone as reference.

Power factor (PF). Power factor (PF) is the ratio of active power and apparent power.

Protective relay. Protective relay is a relay (mechanical or solid state) used to detect abnormalities in a power system or components and initiate appropriate warning or control action.

Psychrometrics. This term refers to the area of physics that deals with the determination of the thermodynamic properties of moist air and the application of that knowledge for analysis and problem solving.

Radiant heat. Radiant heat is heat transmitted by radiation, rather than by Conduction or convection.

Radiation. Radiation is the conveyance of heat by electromagnetic waves in the infared spectrum (between the liHF and visible light bands).

Refrigerant. Refrigerant is a heat transfer fluid used in refrigeration systems.

Relative humidity. Relative humidity is the ratio of the partial pressure or density of the water vapor in air to the saturation pressure of density, respectively, at the same dry-bulb temperature and barometric pressure.

Resistance. Resistance is a measure of the ability of a material or substance to impede or insulate the flow of heat. Resistance is the reciprocal of conductivity and conductance.In the electrical sense, the property of a substance which impedes current and results in the dissipation of power.

Sensible heat. Sensible heat is the heat energy associated with the motion of atoms and molecules in substance.

Sone. Sone is a subjective unit which has a nonlinear scale and is used to compare the levels of sounds. One sone represents the loudness of a 1OOO-HZ zone at 40 dB.

Suppressors. Suppressors are devices or circuits used to reduce or eliminate unwanted signals, noise, or interference. Suppression methods include shielding, filtering, grounding, relocation, and redesign.

Supply air. Supply air is air that is supplied to a room or space through a duct system.

Switching transients. This term refers to an over-voltage in an electric circuit caused by a switching action in the power grid or in user equipment.

Thermostat. A thermostat is a device which monitors and controls indoor temperature.

Transient. Transient is a momentary surge on a communication or power line that may produce false signals or triggering and can cause insulation or component upset or failure.

Transient voltage. This term is generally used to describe a momentary surge in an electrical circuit that exhibits a fast-rising current and voltage waveform.

Trombe wall. A Trombe wall is a concrete, stone, or masonary, south-facing, heat-storage wall up to 16 inches thick, named for one of its developers, Dr. Felix Trombe.

Variable air volume (VAV) system. Variable air volume (VAV) system is a forced-air environmental control system which varies the amount of conditioned supply air to controlled rooms and spaces at constant temperature to maintain design conditions, as opposed to constant volume air at varying temperature.

Voltage sag. This term is generally used to describe a momentary voltage reduction in a power distribution system of 10-35 percent below nominal level.

Voltage surge.This term is generally used to describe a momentary voltage increase in a power distribution system of 10-35 percent above nominal level.

Wet-bulb temperature. Wet-bulb temperature is the temperature registered by a thermometer with its bulb enclosed in a sock, wetted by water, and exposed to a stream of air.

4. GENERAL REQUIREMENTS

4.1 Mission requirements definition. In any facility planning or engineering endeavor, the basis of the design is the definition of the work to-be performed at the facility or installation. The mission assigned to the facility must be evaluated to define the overall requirements for power needs and environmental control to support those requirements. Along with the power requirements, the spaces that will require environmental-control must also be evaluated to determine minimum needs of the equipment and personnel to be employed in the facility. Before any design work can commence, whether for the physical plant or mission systems, it is imperative that a thorough assessment of the mission statement be conducted. This assessment should address the following:

a. Mission function.

b. Mission criticality.

c. Operating organization.

d. Supporting and supported organizations.

e. Location and site survey.

f. Equipment requirements (if known).

g. Personnel requirements.

h. Site-unique requirements.

4.1.1 Mission function. The mission function is a clear and concise statement of the task and purpose of the facility. The statement should define what the facility is to do. From that statement, the facility designer or planner can develop a checklist of facility attributes for further study.

4.1.2 Mission criticality. The criticality of the mission assigned to the facility will be an important factor in the development of requirements for power and environmental control systems. Of particular interest will be the level of survivability required for the facility. Mission criticality is an indication of what protective measures may be required in the design. This criticality will define the role of the facility during periods prior to hostilities or during preattack, transattack, and postattack periods if it has a mission under the Single Integrated Operations Plan (SIOP). If the facility does not have a SIOP mission, its mission criticality will be stated in terms of its mission at each level of Defense Readiness Condition (DEFCON). For example, a facility that is to operate during preattack and postattack periods will require protection against physical destruction. A facility that must operate without failure during the transattack period will require added protection from all components of a nuclear detonation, and may require chemical, biological, and radiological (CBR) protection.

4.1.3 Operating organization(s). The nature of the operatin organization should give the designer or planner information on what ancillary functions, if any, the facility should support. For instance, is maintenance part of the function of the organization? If so, the facility will probably require a maintenance shop and possibly a “clean room for electronic repair. If on-site maintenance is not a function, only a storage area for parts and supplies is needed. The nature of the administration support facility will define what additional space is required.

4.1.4 Supporting and supported organizations. Knowledge of the mission and functions of the supporting and supported organizations is also necessary in the facility design. If a clear determination of the criticality cannot be made from the mission statement, it might be determined from the missions of supported and supporting organizations. The manner in which organizations are supported may also indicate what physical features are required, such as parking and delivery areas.

4.1.5 Location and site survey. The most important step in developing a new DoD facility is the site survey. After a general location has been developed to meet equipment requirements, a physical site survey must be performed. The current version of MIL-HDBK-420, Site Survey Handbook for Communications Facilities, should be reviewed for site conside~ations not specifically covered in this handbook.

4.1.5.1 Geographical and geopolitical considerations. Geographic and geopolitical considerations must be studied and evaluated in determining requirements for power and environmental control systems at all DoD fixed facilities. Climatic conditions will be of considerable interest in the development of environmental control requirements. Geopolitical considerations will be important in evaluating the availability of a continuous power source from the local government or utility, particularly overseas installations.

4.1.5.2 Local power availability. Site survey information will be evaluated to determine the local availability of power supplies and the climatic conditions under which the facility will operate. At the oneset of the project, the team making the site survey will be required to have basic information about the mission of the new or upgraded facility in order to investigate the site correctly.

4.1.5.3 Building construction. Local information will also be required concerning the availability of building materials and construction capability. Use of local materials that will meet the needs of the facility will be considered and evaluated. Consideration should also be given to the use of prefabricated items in establishing the construction needs of the Because of site adaptation requirements, there are no “standard” buildings. However, consideration must be given to fixed DoD floor plans and plats for functional standardization of DoD facilities.

4.1.5.4 Location. The geographic location will determine many of the design characteristics of the facility. For example, the local climate will dictate the heating and cooling requirements. The location will also define the quality and availability of water, electric power, and types of fuel available for heating or emergency power. Location is also important in determining physical security and environmental protection measures.

4.1.6 Equipment requirements. Equipment requirements may or may not be obtained from the mission statement. The statement may be as general as, “operate a medium-scale information processing system in support of....” In such cases, the facility designer or planner can develop abstract plans, but cannot begin the facility design engineering until the equipment to satisfy the mission has been selected.

4.1.6.2 Mission essential equipment. Those materials that are authorized to the facility to accomplish its mission are specifically considered mission-essential equipment. This equipment must be considered in detail when engineering the power and environmental control requirements for a DoD fixed connnunications, automatic data processing, or information systems facility.

4.1.6.3 Administrative support equipment. Those materials that are subordinate to or associated with an end item of equipment, normally a piece of mission-essential equipment, must be considered in defining the requirements of a facility. These materials may include spares, repair parts, tools, test equipment, and materials that are required to operate, service, repair, or overhaul an end-item of equipment.

4.1.6.3 Administrative support equipment. Administrative support equipment consists of materials such as typewriters, duplicating machines, telephones, and the equipment needed to support them.These materials will be considered with regard to their power needs and environmental control requirements.

4.1.6.4 Environmental equipment. Environmental equipment consists of those materials needed for simultaneously controlling temperature, relative humidity, air cleanliness and air motion in order to meet the requirements of occupants and housed equipment. These materials will have unique power requirements and must be considered in the engineering of the facility. Environmental equipment is discussed in more detail in volume III.

4.1.7 Personnel requirements. The number of personnel involved in the operation and the roles they will perform impact the facility design. facility is a 24-hour/7-day operation, with personnel split amen three shifts, smaller personal comfort facilities are needed than if all personnel are present on an 8-hour/5-day basis.
heating, ventilating, and air conditioning (HVAC) requirements. The nature of their duties defines the work station requirements, such as lighting and local ventilation.

4.1.8 Site-unique requirements. Every facility will have certain requirements that are not common to all facilities. These requirements will be addressed as site-unique requirements and will be evaluated individually and within the overall requirements of the facility. These site-unique requirements will be engineered into the total requirements of the site and facility. Site-unique requirements are dictated primarily by mission expectations and geographical location. Some questions used to establish site-unique requirements include:

a. Are sleeping facilities required?

b. Are shower facilities required?

c. Are food preparation facilities required?

d. Are recreational facilities required?

e. Is an auditorium or briefing facility required?

It is not possible to compile a complete list of items that are site unique. Thus, the designer or planner must be alert when formulating the facility design for clues as to special features needed. Close cooperation with the user will provide insight into additional requirements and site features.

4.2 Power requirements. Once the mission requirements have been established, the facility design continues with the determination of power requirements. Power requirement development begins with mission equipment power demands, followed by power load of other supporting utilities (i.e., heating, cooling, lighting). This sequence is necessary because heating and cooling systems are sized for the equipment and personnel operating the equipment. Lighting needs are dictated by the illumination levels that must be present for personnel to perform their tasks accurately and efficiently. Appropriate service documents, such as AFR 88-15, should be consulted for lighting levels. Finally, power consumption data for all groups of equipment are consolidated into one table: the total facility power load. Power consumption data varies with manufacturer and type of equipment. Information required to determine equipment consumption is available in a variety of combinations, such as:

a. Voltage.

b. Phase.

c. Frequency.

d. Current.

e. Wattage.

f. Power factor.

g. Horsepower.

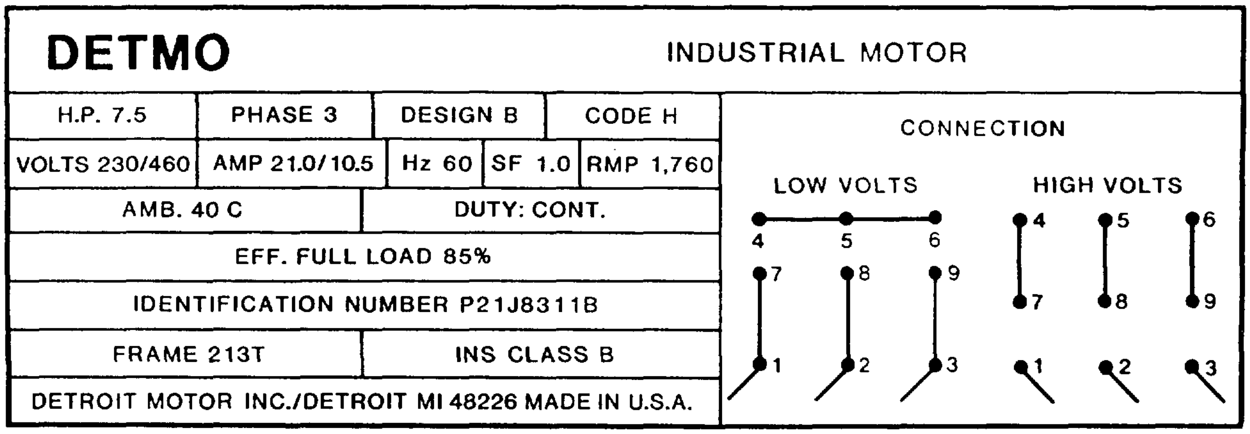
h. Heat dissipation.

Operating ac voltage is universally shown on equipment rating plates and in manufacturers' brochures. The number of phases is not always indicated, unless polyphase service is required. Frequency may be given if the equipment operates at other than 60 Hz. Current and wattage are often provided singly but seldom in combination. The power factor (PF) is not usually provided, but can be calculated. Most larger motor-driven devices will be marked with a horsepower rating from which other data can be calculated. An example of motor nameplate data required by NEC article 430-7 is shown in figure 1. The National Electrical Manufacturers Association (NEMA) and The American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) both publish standards that address efficiency and performance expectations for electric motors.

4.2.1 Voltage. American-made equipment will be marked as requiring 110 volts, 117 volts, 120 volts, or 125 volts ac. For data collection, any such marked device can be served from a 120-volt single-phase service. For other data elements which must be calculated (i.e., power factor), the given voltage rating will be used.

4.2.2 Transformers. To effectively transmit ac power from a remote generator to a distant load, transformers are installed at both ends, as shown in figure 2. This arrangement permits an increase in transmission line voltage whicg can be changed at the user location to match the voltage required by the load. For the same power, this higher-voltage line carries less current, has less loss for the same size wire, and provides more stable voltage conditions at the load. One of the most important reasons for using ac for power distribution is its ability to be readily adapted to loads having different voltage requirements by use of the transformer. In addition to load-matching applications, transformers are used extensively to sample power-system conditions (instrument transformers) and to improve isolation of critical loads from the noise and transients present on the power distribution network.

4.2.3 Phase. Most ac-powered equipment operates on electricity from a single phase to neutral which is derived from a wye transformer connection. Some equipment may be marked 120/208 V or 277/480 V, usually indicating that it requires one or more phases derived from a wye connection. U.S. equipment marked 240 V typically is powered across three phases, and a delta connection, without neutral or common, is inferred. The number of required phases becomes important when the facility power distribution and load balancing are engineered. The basic connections of secondary power distribution transformer windings are illustrated in figure 3. Additional information on power transformers is contained in paragraph 4.6.4 of this volume and in volume II.



DETMO INDUSTRIAL MOTOR

H.P. 7.5	PHASE 3	DESIGN B	CODE H	
VOLTS 230/460	AMP 21.0/10.5	Hz 60	SF 1.0	RMP 1,760
AMB. 40 C		DUTY: CONT.		
EFF. FULL LOAD 85%				
IDENTIFICATION NUMBER P21J8311B				
FRAME 213T		INS CLASS B		
DETROIT MOTOR INC./DETROIT MI 48226 MADE IN U.S.A.				

FIGURE 1. Motor nameplate information.

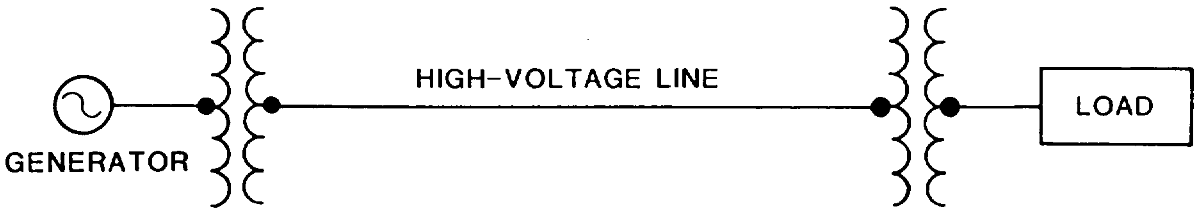
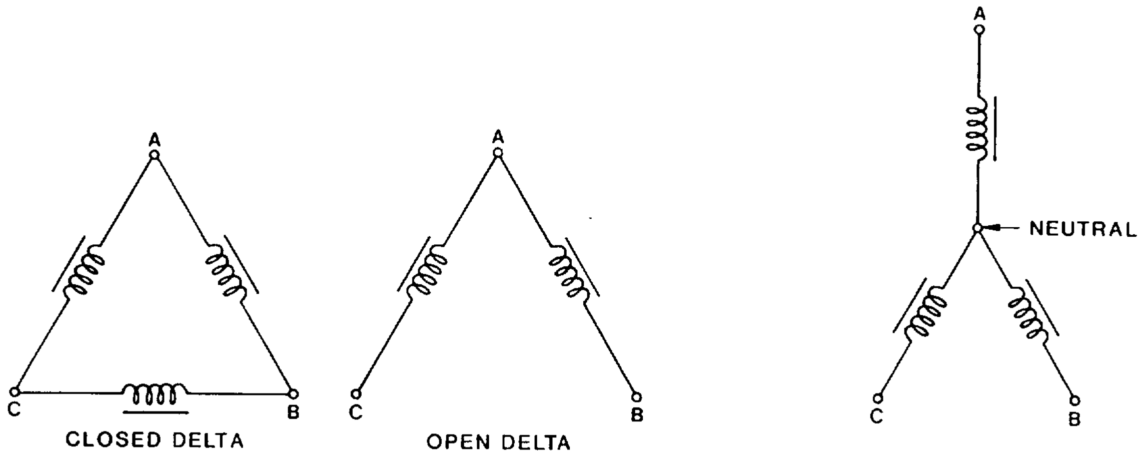


FIGURE 2. Use of transformers in ac distribution.



A. 3-PHASE DELTA DISTRIBUTION
TRANSFORMERS.

B. 3-PHASE WYE DISTRIBUTION
TRANSFORMER.

FIGURE 3. Delta/wye transformer connections.

4.2.4 Frequency. The electrical frequency of ac-powered equipment becomes an issue when operating in foreign countries or when a facility is multinational. U.S.-made equipment may require the installation of frequency converters if not manufactured for dual frequencies (60 Hz and 50 Hz). Some U.S. equipment may require 400-Hz service, such as equipment designed for airborne use, installed in ground-based facilities.

4.2.5 Current. Information concerning current is stated in amperes (A). However, there is no distinction between real current and apparent current. These data are needed when power factor is a consideration.

4.2.6 Wattage. Wattage ratings are a true indication of the power required to operate equipment and are directly correlated to heat dissipation. When used with voltage and current readings,wattage can be used to calculate the power factor.

4.2.7. Power factor (PF). Power factor is defined as the ratio of the actual power used in the circuit, in watts (W) or kilowatts (kW), to the apparent power delivered by the utility expressed in volt-amperes (VA) or kilovolt-amperes (kVA). It is an indication of the efficiency at which ac powered equipment operates. The power factor results from the lead or lag of current to voltage through capacitive or inductive loads and is commonly expressed as a decimal or percentage.As illustrated in figure 4, the power factor is also the cosine of the phase angle. The greater the angle becomes, the worse, or more lagging, the power factor becomes. In a growing number of locations, a utility customer pays higher rates for a low power factor. Unfortunately, power factor is often the one data element not normally provided by the equipment manufacturer. The effects of power factor on connected equipment and methods to improve power factor are covered in volume II of this handbook.

4.2.8 Heat dissipation. To size the HVAC system, the heat dissipation of all the equipment must be known. Heat dissipation is expressed in British Thermal Units (Btu) per hour and is directly related to wattage. (See 4.2.9.3).

4.2.9 Conversions. There are many simple electrical relationships that may be used to obtain missing data. The most useful of the conversions are contained in appendixes to this handbook.

4.2.9.1 Wattage. If wattage is not given, the product of the voltage and current gives the apparent ac power, expressed in volt-amperes (VA) or kilovolt-amperes (kVA). This is not the real power consumed, unless the load is purely resistive.

4.2.9.2 Power factor (PF). If the PF is not given with equipment specifications, it can be calculated from the voltage, current, and wattage parameters. If the product of current and voltage (apparent power (VA)) is greater than the listed wattage, the power factor is determined by the following relationship:

$$\text{Percent PF} = W/VA \times 100$$

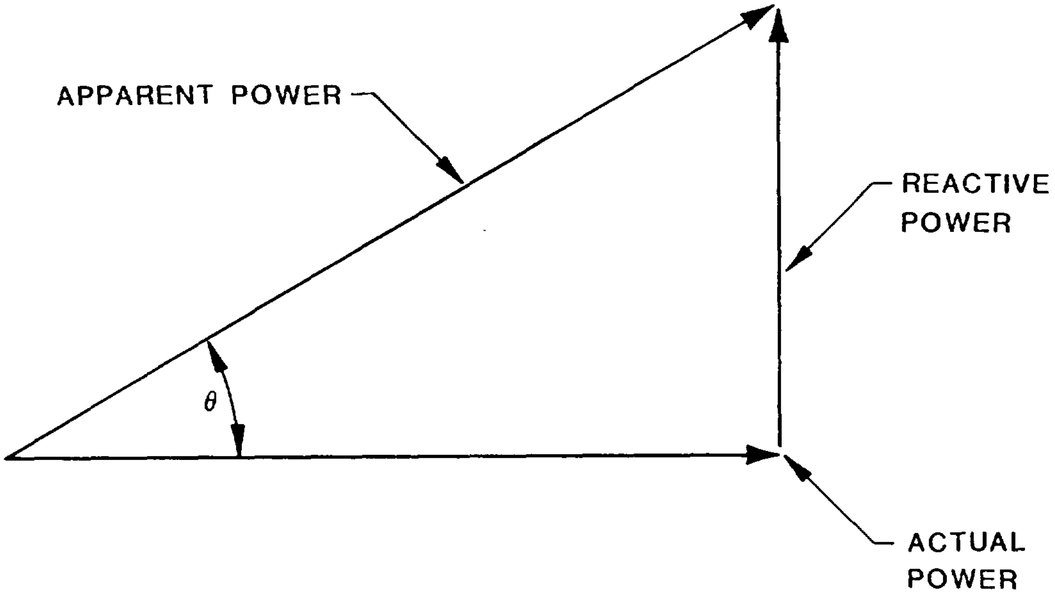


FIGURE 4. Leading power factor triangle.

If both current and wattage data are missing, the manufacturer should be asked to provide the missing information. (See figure 4.)

4.2.9.3 Heat dissipation. Heat dissipation is commonly expressed in watts, and can be dtermined from current, wattage, or horsepower ratings. horsepower is equal to 746 watts and one watt equals 3.412 Btu/hr. Accordingly, one horsepower equals 2545.35 Btu/hr. If wattage is unknown, the apparent power (VA or kVA) can be used to calculate heat dissipation, but the estimate will be high. The resulting inaccuracy is power factor dependent.

4.2.10 Data collection. Data should be collected on all equipment and support functions by room or operational area for proper power and environmental control distribution. In order to properly classify the facility load, a hierarchy of electrical loads is required. This hierarchy is graphically illustrated on figure 5.Additional information on DoD power systems is contained in construction criteria manuals of the individual military departments, such as NAVFAC DM-4.1, Preliminary Design Considerations, Information on modernization of existing DoD power systems is contained in Electrical Power Modernization Program for Critical Comnand, Control, and Conmnunications Facilities (DoD instruction 4630.7, December 28 1986). Sample DoD power consumption data collection sheets are at appendix A. Information from this collection sheet may also be used to size emergency generators, transfer switches, uninterruptible power supplies (UPS), and for load balancing. Personal computer (PC) programs are also available to compute power loads for a facility.

4.3 Primary local power characteristics and sources. Except in extremely isolated areas, commercially generated power will be the most cost effective primary source for DoD installations. However, the commercial source must be reliable enough to result in minimal use of facility power generation equipment during normal operations. A facility should be served by two separate commercial power sources with physically separated independent feeders. If two commercial power sources are not available, physically separated feeders from the power substation to the site power plant are required. This arrangement will permit power distribution maintenance or repairs with minimal mission impact. Figure 6 is a block diagram of a typical power generation, transmission, and distribution system. A checklist of the factors that should be considered during initial planning and the site survey phase for a DoD facility is at appendix D.

4.3.1 U.S. commercial power grid. DoD facilities that are located in the Continental United States, Alaska, and Hawaii may rely on the U.S. cormnercial power grid as a primary source of power.In general, this power should be quite stable, and should pose little threat to facility power reliability. It is important, however, to conduct a thorough evaluation of available power. Most power distribution networks are routed through a power substation. Although the substation may be designed to provide powerline protection, regulation, and load balancing, it may also be a source of interference in the form of RFI/EMI or switching transients. For this reason, the facility should be located a reasonable distance from the substation because power feeder electrical properties tend to reduce these undesirable characteristics as a function of length. On the other hand, too

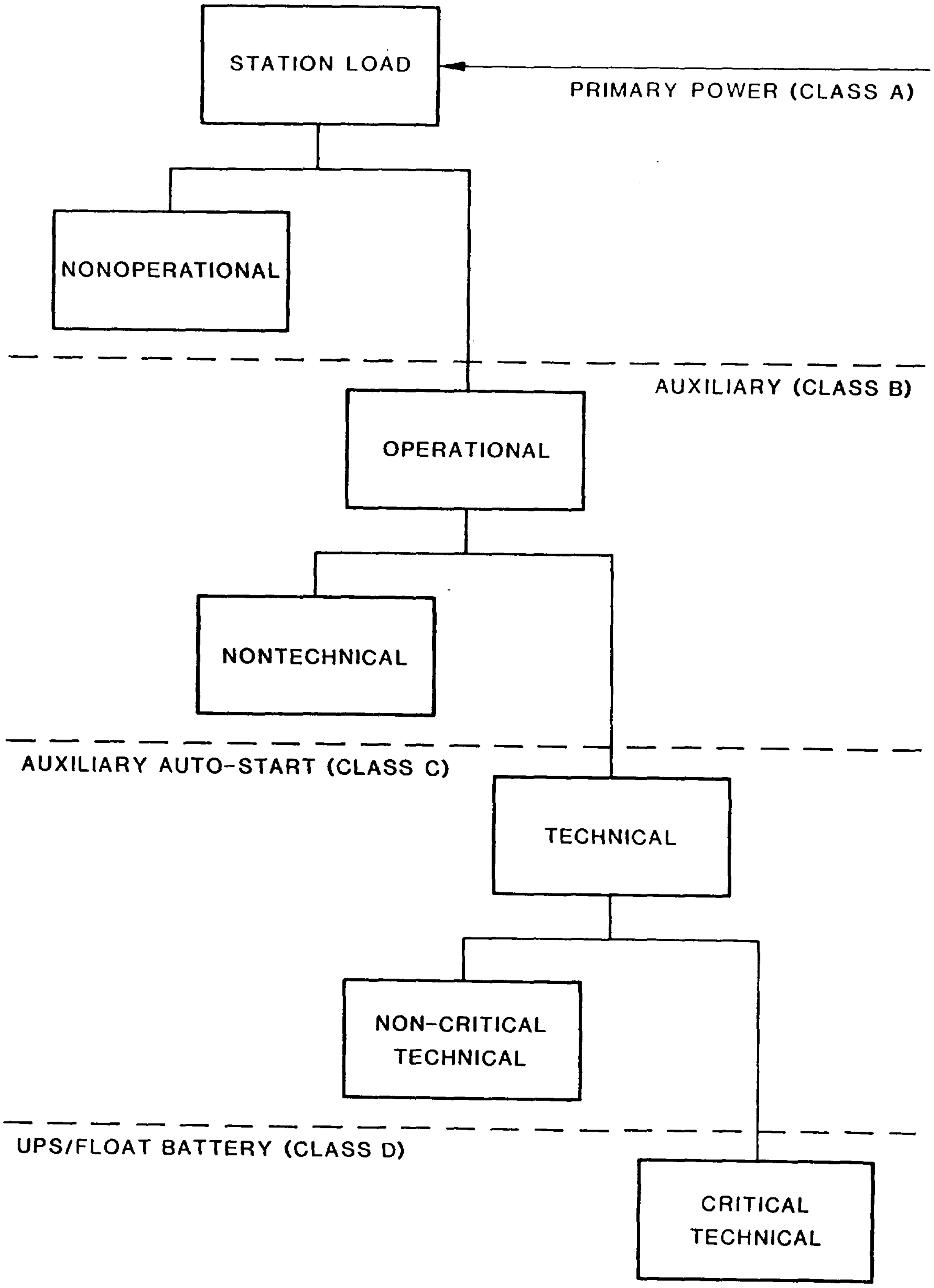


FIGURE 5. Power heirachy diagram.

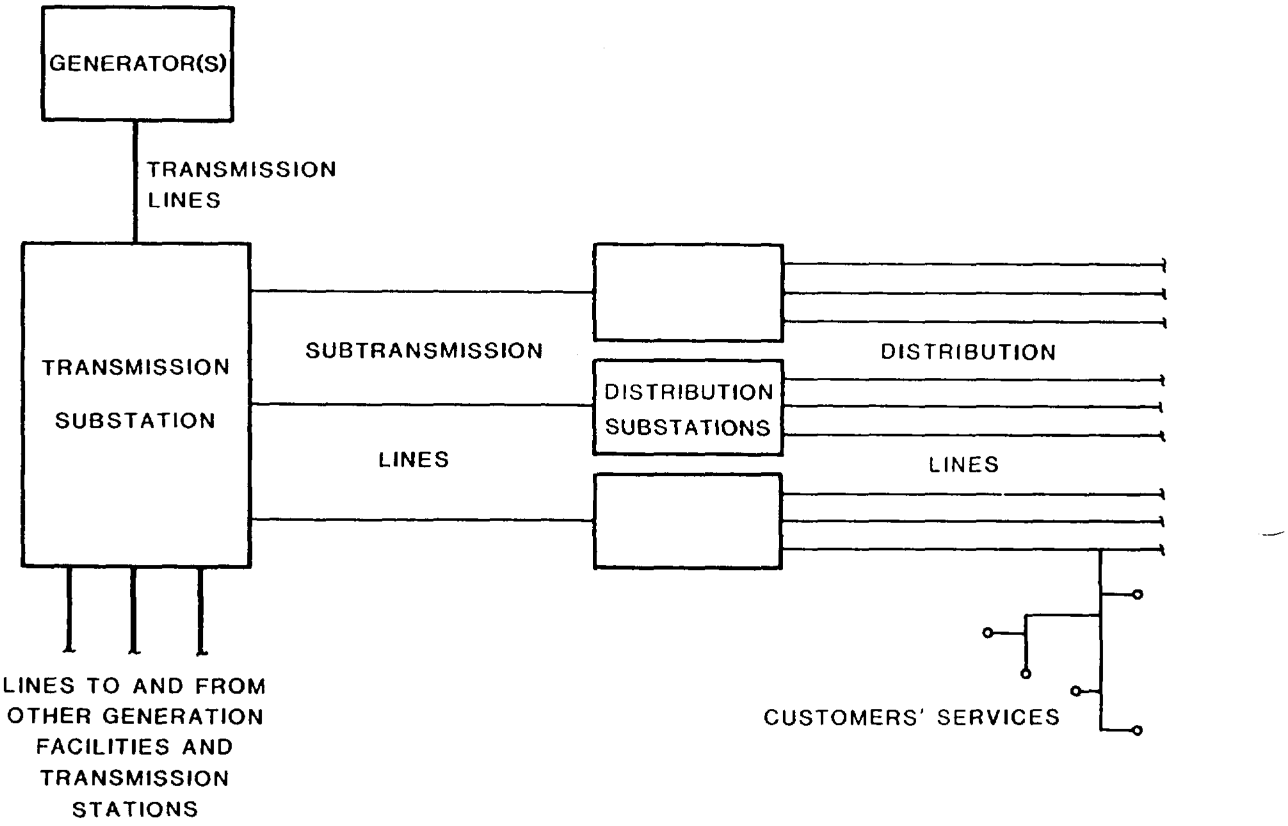
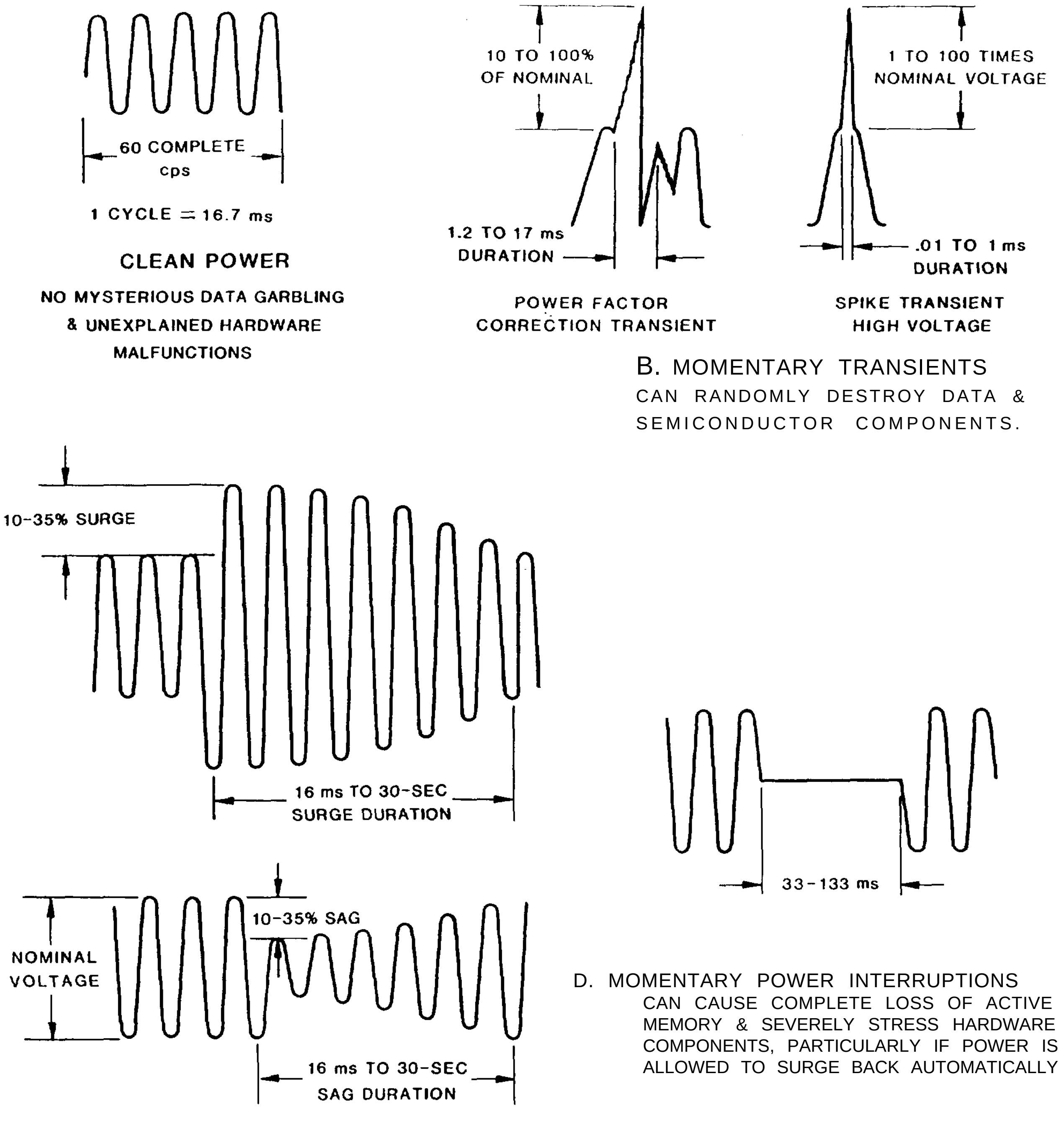


FIGURE 6. Transmission and distribution system block diagram.

great a distance from the substation may result in unacceptable line loss and low voltage at the facility. During the site survey phase, a one-line diagram of the power system serving the facility should be obtained. This diagram should include distances, voltages, frequency, substation locations, and transformer capacities between the substation and the site. If for some reason this information is not available from the serving company, it must be pieced together by personal observations, measurements, and questions to present customers. Portable test and monitoring equipment is available to detect harmonics, transients, surges, and interruptions during the site survey phase of the facility development. Figure 7 graphically represents some of the terms used to describe power quality and stability. If the utility power distribution system does not exist prior to the site survey, monitoring should start during the construction phase so that corrective measures may be taken prior to the facility operational date.

4.3.2 U.S. Government-owned and operated power system. When a new DoD facility is being built at an isolatedlocation, or being addes on an isolated Government installation, it is likely that all power must be provided by the Government. Depending on host-tenant agreements, the DoD facility commander may be responsible for all local power production or, as a minimum, will work with installation power production personnel to achieve the required power quality. The DoD facility site commander will appoint a power coordinator to work with facility engineering personnel to ensure availability of a dependable power system.The U.S. ARMY Information Systems Command Pamphlet 420-1 contains as an example of power quality topics to be covered in written procedures for each DoD facility. In any event, the comments in the preceding paragraph on power characteristics to consider during the site survey phase apply. On the plus sick, vulnerability of the Government-provided power distribution system should be less, due to containment within the facility, and control over equipment-generated power interference should be absolute. Other considerations when planning a primary power production plant are increased storage for spares and fuel, as well as the ability to maintain the plant during stress conditions. In the event of a total site ower failure, restoration must follow the load hierachy (see figure 5). For energy conservation reasons, all planning for new or replacement Government power plants must consider the possibility of heat recovery. Cogeneration is the simultaneous production of usable heat and electricity from the same fuel source. Further information on cogeneration can be found in 4.9.9 and in volume 11 of this handbook.

4.3.3 Foreign power grid, The power frequency and voltages encountered in host countries should not be a problem to the planner of DoD facilities provided their characteristics are determined during the site survey and the equipment being installed is ordered with the correct options. In the unusual case where equipment cannot operate on the frequency of a foreign power grid, frequency converters (as discussed in 4.5) must be used, resulting in an increase in power consumption. Voltage differences can usually be resolved easily with stock transformers (see 4.6.4). During the preliminary planning phase for a DoD facility, individual service manuals, such as FM 11-486-7/T.O. 31Z-10-22 and FM 11-487-4/T.O. 31-10-24, should be consulted for host country power characteristics.Even though this information can be useful in planning, final equipment selection must be based on information gathered during the site survey.



B. MOMENTARY TRANSIENTS
CAN RANDOMLY DESTROY DATA &
SEMICONDUCTOR COMPONENTS.

D. MOMENTARY POWER INTERRUPTIONS
CAN CAUSE COMPLETE LOSS OF ACTIVE MEMORY & SEVERELY STRESS HARDWARE COMPONENTS, PARTICULARLY IF POWER IS ALLOWED TO SURGE BACK AUTOMATICALLY

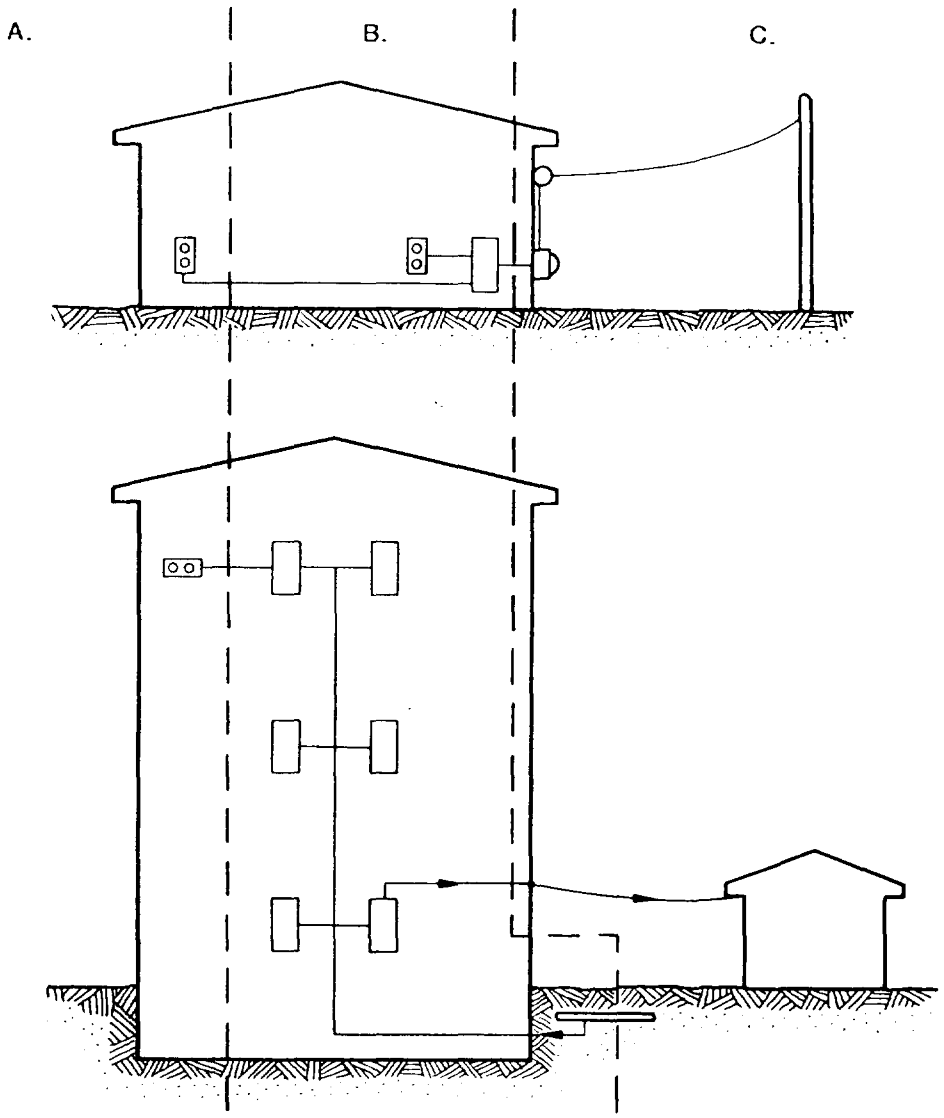
C. VOLTAGE SAGS & SURGES
CAN CAUSE DATA GARBLING &
STRESS HARDWARE COMPONENTS

FIGURE 7. Graphic explanation of power quality terms.

4.4 Power disturbances and monitoring. Power distrbances are a major threat to DoD facilities because such disturbances may cause a loss of data, equipment damage, or system upset. Power anomalies fall into five basic categories: (1) power interruption (blackouts), (2) low or high voltage (sags or surges), (3) transients (impulses), (4) harmonic distortion, or (5) noise. (See figure 7.) Power disturbances may be generated by the power source, lightning, electromagnetic pulse (EMP), electrostatic discharge (ESD), motor-driven and nonmotor-driven equipment, and nearby facil itles. Several industry standards to define and test for power disturbances are still under development, but one of the early standards, ANSI/IEEE 587-1980, has established some commonality among manufacturers. This standard (IEEE Guide for Surge Voltages in Low-Voltage AC Power Circuits) characterizes the power line surge environment as category A (long-branch circuits , category B (short-branch circuits), and category C (outdoor, overhead lines) . Figure 8 illustrates these categories. Along with the establishment of categories, this standard establishes specific waveforms so that protective devices can be tested on an equitable basis. Table I lists the surge voltages and currents that represent the indoor environment using the IEEE standard. It should be noted that voltage in this table is theoretically limited to 6 kV due to arcing between conductors (or between conductors and ground) in the indoor environment. The use of a power-quality monitor during the site survey phases is highly desirable and is mandatory for a completed facility. Both portable and rack-mounted units are useful in determining the source and type of power perturbations. The data gained from the on-line monitor can be used to correlate unexplained DoD hardware and software malfunctions. Automated power-factor correction can also be effected using currently available on-line monitors.

4.4.1 Lighting. Weather-related power disturbances cause more problems with sensitive electronic equipment than any other source. Even if storm fronts cause some power problems due to electrostatic buildup, it is lightning that causes the serious sags, surges, and spikes. There is no known method to prevent lightning damage to equipment and structures, but good engineering practice provides an attractive path for lightning discharge to cart that will limit damage to an acceptable level. Lightning protection techniques are discussed in 4.15. Further guidance concerning lightning protection is included in volume II of this handbook.

4.4.2 System-generated disturbances. System- or source-generated disturbances may also be in the form of sags, surges, frequency variation, high or low voltage, outages, or harmonic distortion. Such conditions, with the exception of harmonic distortion, may be the result of faulty generation or regulation equipment, poor wiring techniques, improper grounding, or overloaded or unbalanced circuits. Harmonic distortion is an inherent characteristic of power generating equipment. Typically, odd harmonics (third, fifth, seventh, et seq) are of enough amplitude to create distortion which will affect the performance of some electronic equipment. Isolation from the power grid using transformers, motor generators, UPS etc., usually solves power quality problems. Even with on-site backup power systems, one of the main operational problems is total harmonic distortion (THD). Power monitor options are available to report when THD exceeds a programmed threshold.



OUTLETS AND LONG BRANCH CIRCUITS	MAJOR FEEDERS AND SHORT BRANCH CIRCUITS	OUTSIDE AND SERVICE ENTRANCE
ALL OUTLETS AT MORE THAN 10 m (30 FT) FROM CATEGORY B WITH WIRES #14-10	DISTRIBUTION PANEL DEVICES	SERVICE DROP FROM POLE TO BUILDING ENTRANCE
ALL OUTLETS AT MORE THAN 20 m (60 FT) FROM CATEGORY C WITH WIRES #14-10	BUS AND FEEDER SYSTEMS IN INDUSTRIAL PLANTS	RUN BETWEEN METER AND DISTRIBUTION PANEL
	HEAVY APPLIANCE OUTLETS WITH "SHORT" CONNECTIONS TO THE SERVICE ENTRANCE	OVERHEAD LINE TO DETACHED BUILDINGS
	LIGHTING SYSTEMS IN COMMERCIAL BUILDINGS	UNDERGROUND LINES TO WELL PUMPS ETC.

FIGURE 8. Power distribution location categories.

TABLE I. Surge voltages and currents representing indoor environment.

LOCATION CATEGORY	COMPARABLE TO *IEC 664 CATEGORY	IMPULSE		TYPE OF SPECIMEN OR LOAD CIRCUIT	ENERGY (JOULES) DEPOSITED IN A SUPPRESSOR WITH CLAMPING VOLTAGE OF	
		WAVEFORM	MEDIUM EXPOSURE AMPLITUDE		500 V	1000 V
					(120 V system)	(240 V system)
A. Long branch circuits and outlets	II	0.5µs - 100 kHz	6 kV	High impedance	--	--
			200 A	Low impedance	0.8	1.6
B. Major feeders short branch circuits, and load center	III	1.2/5µs	6 kV	High impedance	--	--
		8/20µs	3 kA	Low impedance	40	80
		0.5µs - 100 kHz	6 kV	High impedance	--	--
			500 A	Low impedance	2	4

*International Electrotechnical Commission

4.4.3 Power grid generated disturbances. The power grid contains transients that are reflected into it by users. Power switching by the user, or the utility, generates a voltage spike that is detectable throughout the local network. Other sources of noise, spikes, harmonics, and sags result from heavy electric motors turning on and off, elevators, electric welding, or any nearby operation that produces an arc. Suppressors used in lighting -and-EMP-caused transients will not protect against sags, electrical noise, or spikes below the threshold voltage of the device. Isolation transformers (see section 4.5 of this handbook) may be helpful in reducing low-level spikes and noise, but are of little value during sags and surges. To assist in identification of the interfering source, the facility power system monitor should have directional capability.

4.4.4 Protection techniques and location of devices. Due to the possibility of equipment failure or human error, it is necessary to provide overcurrent protective devices. These devices minimize damage when a failure occurs, by isolating the affected circuit while maintaining service to the rest of the system. Protective relays, fuses and circuit breakers are used to provide this type of protection. The ground-fault protection relay is a special device used to protect motors, power filters, transformers, and personnel. In the equipment case, the relay detects failure of the insulation of a machine, transformer, or other apparatus to ground. In the personnel safety application, these relays are called ground-fault circuit-interrupters (GFCIS) and are required by the NEC in hazardous locations. The second category of protective devices limits transients by attenuation (filters) or diversion (voltage clamping). Although brief, transients as small as one nanojoule of energy are sufficient to upset transistors, integrated circuits, and semiconductors. Because there are so many sources for potentially destructive transients, the best solution is to isolate the critical technical load (see figure 5) from the power grid. Even when this load has been isolated, it is desirable to suppress transients to all of the station load to reduce the chance of damage to nontechnical equipment or to the isolation equipment itself.

4.4.4.1 Fuses. Within the first half cycle (1/120th of a second) of an electrical fault, surge currents in a power distribution system have been observed to be in the 200,000-ampere range. With these high surge currents to deal with, downstream circuit protection is extremely important. It is also important to understand what available fault current really means. The amount of short circuit current is not necessarily determined by the facility distribution system because the utility may have sized the power distribution to serve several local users. This means that the available fault current is increased proportionally. The job assigned to the current-limiting device (fuses, circuit breakers, and relays) is to force the current to zero before its normal return time. In the case of a 60-Hz line frequency, the design objective is to accomplish this prior to the first zero crossing or 8.3 milliseconds after detection of a fault while withstanding these high currents without being physically destroyed. The two basic types of fuses are current limiting and noncurrent limiting. Noncurrent-limiting fuses are usually the replaceable type and operate in one or two cycles where current-limiting types are very fast--acting in less than a quarter cycle.

Interrupting ratings of both types are expressed in symmetrical amperes, but they are capable of interrupting 1.6 times their rating on a symmetrical fault current. Fuses continue to have a very definite role in modern power distribution and can be used to protect against the possibility of erratic or slow operation of circuit breakers. Fuses for transformer protection have recently been developed that have an interruption module and a solid-state control module. The interrupting module only reacts to a fault current detected by the control module. They are available for the 4-to-25 kV range and feature extremely fast reaction to overcurrent conditions. Volume II of this handbook contains information on classes, location, selection, and sizing of overcurrent protective devices. Section 240 of the NEC addresses the location and application of fuses.

4.4.4.2 Circuit breakers. Circuit breakers classed as “current-limiting” depend on electromagnetic repulsion to clear a fault current. With a rapidly increasing current through the breaker, the opposing magnetic fields move the contacts apart quickly. In fact, to meet specifications, the action must occur in less than 8.3 milliseconds. Although circuit breakers are rated by the current they will interrupt (interrupting capacity (ICI), system voltage is of equal importance as the stated current rating must change with a change in voltage. As defined, current-limiting breakers are designed to clear the circuit before peak current occurs. This means that if an underrated breaker is specified, the fault current may physically destroy the protective device. Other than reaction time, circuit breakers have several advantages over fuses with the main advantage being quick reset following fault identification and clearance. New molded-case breakers will perform as expected under short- circuit conditions and more expensive solid-state versions can protect against such things as jammed machinery, single- or multiple-phase failure, and phase sequence reversal. Vacuum and oil surrounded breaker contacts are used in some high-voltage applications to help extin uish the arc that results during contact opening and closing actions. Breakers that have been installed for several years are notorious for failure to open when a fault occurs. Most of these failures can be traced to improper maintenance or installation in a corrosive location. The solution to providing a safe fault protection system is to use the correct protector for a specific location or function. This solution starts with the preparation of a one-line power diagram for the facility. When this drawing has been completed, an analysis is made at typical points where a short might occur. This diagram, coupled with knowledge of available fault current and equipment characteristics, permits selection of the correct current-limiting device. The trend in custom circuit breaker design is from analog to digital devices. In addition to being programmable, the digital versions can provide integral ground-fault protection. Several sections of the NEC pertain to the application and selection of circuit breakers. ANSI, IEEE, and NEMA have all produced standards and articles on the subject.

4.4.4.3 Protective relays. Protective relays are also used to limit current, operate power breakers, and react to abnormal voltage, frequency, or phase conditions. Most versions of protective relays are equipped with adjustable thresholds. Electromechanical relays are used extensively in multiphase motor protection, in automatic transfer switches, and in

TABLE II. Advantages of solid-state protective relays.

Quick reaction to power changes
Adjustable settings (thresholds)
Low power drain (saves on instrument transformer costs)
Integral test circuitry
Take up less panel space
Can be equipped for remote programming
Immunity to seismic activity
Consistent performance
Available for hazardous locations as defined in NEC

ground-fault (current) detection. Some of the advantages offered by solid-state protective relays over electromechanical versions are listed in table II. Additional applications of protective relays are discussed in 4.5.4.3 and volume II of this handbook.

4.4.4.4 Surge suppressors (arresters). Previous discussions extolled the virtues of solid-state protective devices, but these devices are in intimate contact with the power distribution system. This means that transient protection in the form of surge suppressors must be installed ahead of solid-state protective devices to ensure survivability. Most of the solid-state protective relays and circuit breakers have internal bipolar zeners or metal oxide varistors (MOVS) to protect circuitry from low-level transients. Surge suppressors (arresters) are available to protect everything from high-voltage power distribution systems down to the smallest electronic component (circuit board level). The selection process for the correct protection devices is complicated, but logical. For example, the designer must start with the generalized characteristics of the expected threat from lighting or EMP. Due to major differences in reaction time of the various types of protectors, waveshape definition is extremely important in the design process. A surge impinging on a power system in reacting with the natural system resonances can result in an oscillatory surge. The indoor power environment (120-240 V), reacting to a unipolar surge or transient, tends to produce an oscillating, decaying, polarity-reversing wave such as shown in figure 9. IEEE and ANSI standards define several waveforms that are typical for different environments. Though the definitions are based on averages, industry commonality for device testing is assured. See table I for additional information. The facility one-line power diagram can be used to determine where properly rated protective devices are to be placed. The term “properly rated” refers to device voltage rating, reaction time, and energy handling capability (usually stated in joules). Volume II of this handbook contains additional information on transient protective device application and selection.

4.5 Power conversion, conditioning, and regulation. Most. DoD facilities will require some form of power conversion to attain compatibility between installed equipment and the primary power source. The most common conversion is changing ac power to dc. This is accomplished in several ways, depending on the load. Smaller dc power supplies generally fall into the linear, ferroresonant, or switching categories. The latter category, although very flexible and efficient, requires considerable filtering and shielding to reduce EMI to a tolerable level. The simplest conversion changes ac distribution voltage to the ac level required by the equipment. This conversion is accomplished economically and efficiently by the use of a step-up or step-down transformer. Larger scale dc conversions rectify ac and then use the dc to charge batteries which provide a specified amount of power carry-through during ac power fluctuations and outages. The ac to dc conversion to charge batteries can then be carried a step further with the addition of a rotary or static inverter to feed conditioned ac power to critical equipment. This configuration is referred to as an uninterruptible power supply (UPS). Ac power regulation, usually accomplished by varying supply transformer parameters, can be very important to certain types of

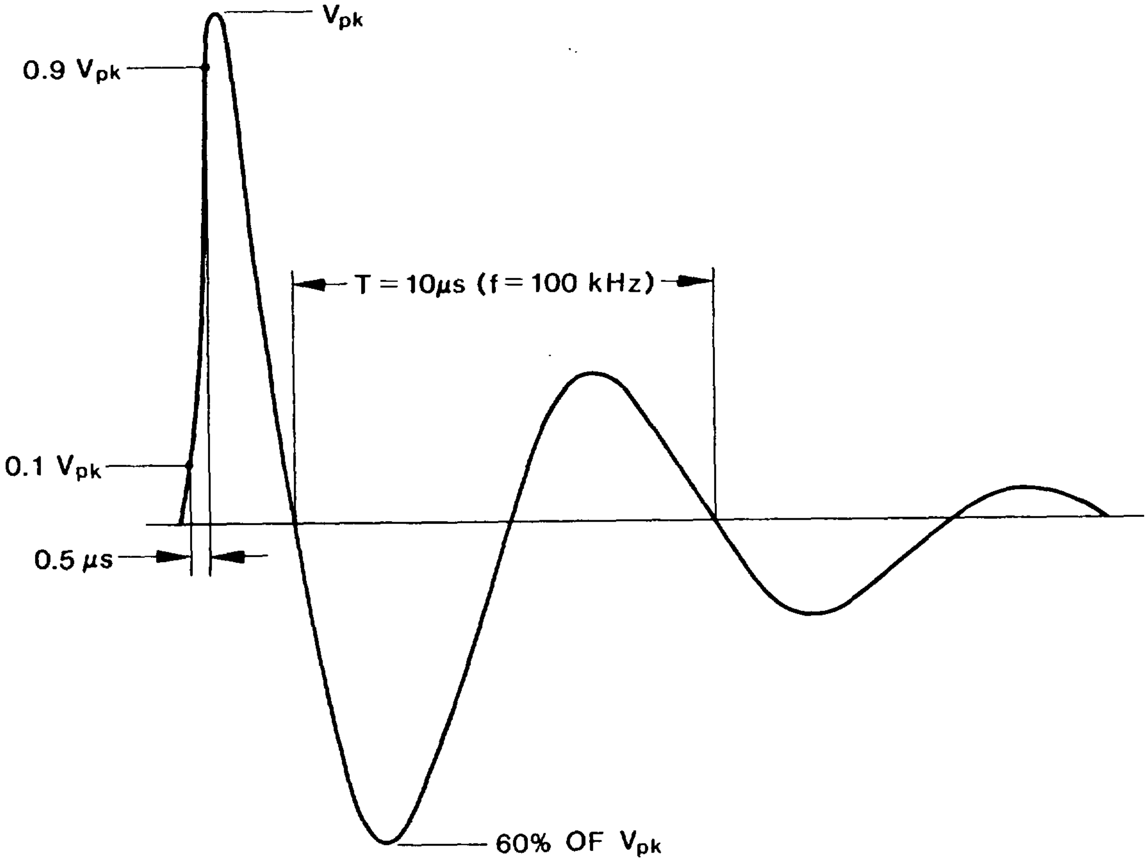


FIGURE 9. Representative indoor surge waveform.

equipment, as illustrated in table III. Although these variable-step transformers have definite DoD applications, their response is too slow to eliminate the effects of momentary interruptions and fast-rising transients. The ultimate conditioning and regulation of ac supply voltage use several devices to control, isolate, and protect the input to subscriber equipment as illustrated in figure 10. Power conversion for noncritical loads must be carefully weighed due to initial costs, and with converter (inverter) efficiencies ranging from 65 to 95 percent, there will be proportionally higher utility costs.

4.5.1 Special power considerations for communications and computer-based equipment. Space allocated for computer-based equipment is unlike any other area in a facility. Due to the sensitive nature of this equipment, special electrical/mechanical systems are required. Special air distribution systems with more rigid humidity and air filtration control are necessary (see 4.13.4). A fire detection system is required for computer areas. A system called Very Early Smoke Detection Apparatus (VESDA) is currently in favor to trigger fire control systems (see appendix B). Grounding of power distribution equipment must strictly follow MIL-STD-188-124 and NEC Section 250 criteria. Proper grounding is essential for personnel and equipment safety, as well as control of static electricity, and noise. The previously mentioned full-time power monitor is a useful tool in linking unexplained computer malfunctions to power system disturbances. Uninterruptible power supplies are a must for critical DoD computers. An UPS provides clean power for a specified interval after a primary power interruption. The type, sizing, and sophistication of uninterruptible power is a function of how important the computer is to the mission. As a minimum, as UPS battery system should provide ample reserve to maintain power levels until an emergency power source comes on line. Some computer manufacturers are recommending dedicated power distribution systems. These systems serve only the computer area and have a dedicated power distribution panel (usually fed by an UPS) and orange-colored outlets for identification. Orange-colored outlets are isolated ground outlets, which are not normally reconmnended for DoD installations. A dedicated system offers some advantage in that no other noise-generating system is on the same circuit. Federal Information Processing Standards (FIPS) Publication 94 should be reviewed when planning a computer-based information system.

4.5.2 Uninterruptible power supply (UPS). As implied, and UPS will be provide a continuous ac output when the primary ac source is interrupted. During outages or sags, power for the UPS inverter is from batteries. This method of maintaining computer power quality has the advantage of no switching time when the primary power is interrupted. Additionally, the battery bank is an effective absorber for power line noise and transients. See figure 11 for basic UPS modes of operation. Mission requirements will dictate the type of UPS needed and whether single or multiple modules are required. A sample DoD power consumption data collection sheet (appendix A) is useful in sizing an UPS, once mission requirements have been established. In filling out these forms, care must be taken to ensure that environmental systems essential to critical load functions are included. Other than cost, the only other major caution in selecting an UPS is to make certain that the harmonic content of

TABLE III. Generalized effects of fluctuating ac voltage.

Equipment	With 10 percent undervoltage	With 10 percent overvoltage
Resistance heating	Equivalent heating takes 25 percent longer	Heating elements experience excessive oxidation
Lighting	15 percent more fluorescent and 30 percent more incandescent lamps required to obtain same illumination level	Fluorescent ballasts operate at elevated temperature and incandescent lamp life can be reduced by 70 percent
Magnetic devices	Relays operate slowly, may chatter and open contacts	Contact surfaces wear faster and insulation breakdown may occur
Motors	Starting torque reduced by 19 percent and higher operating temperature	12 percent increase in starting current and higher torques may stress shafts, gears
Electronics equipment	Output may be decreased by 20 percent or an oscillator may drop out	Failure of ICs, capacitors, and other components is greatly accelerated

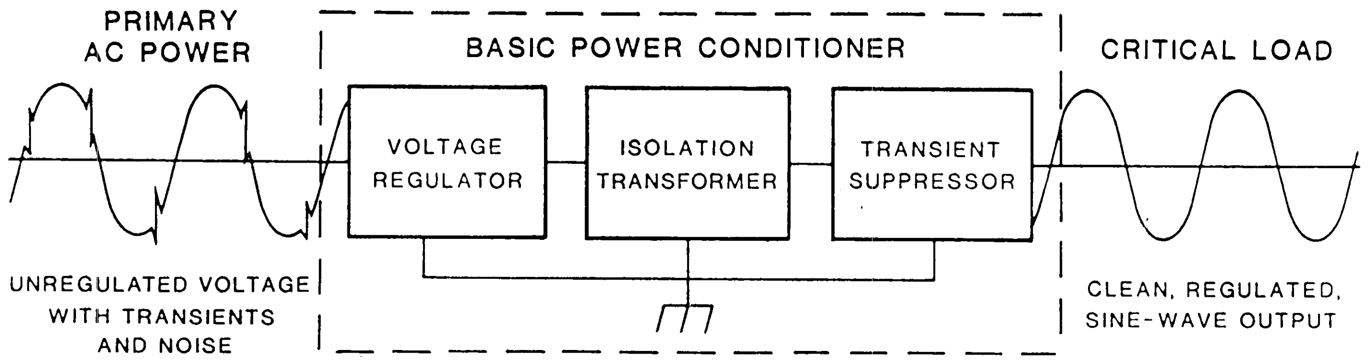


FIGURE 10. Regulation, isolation, and protection configuration.

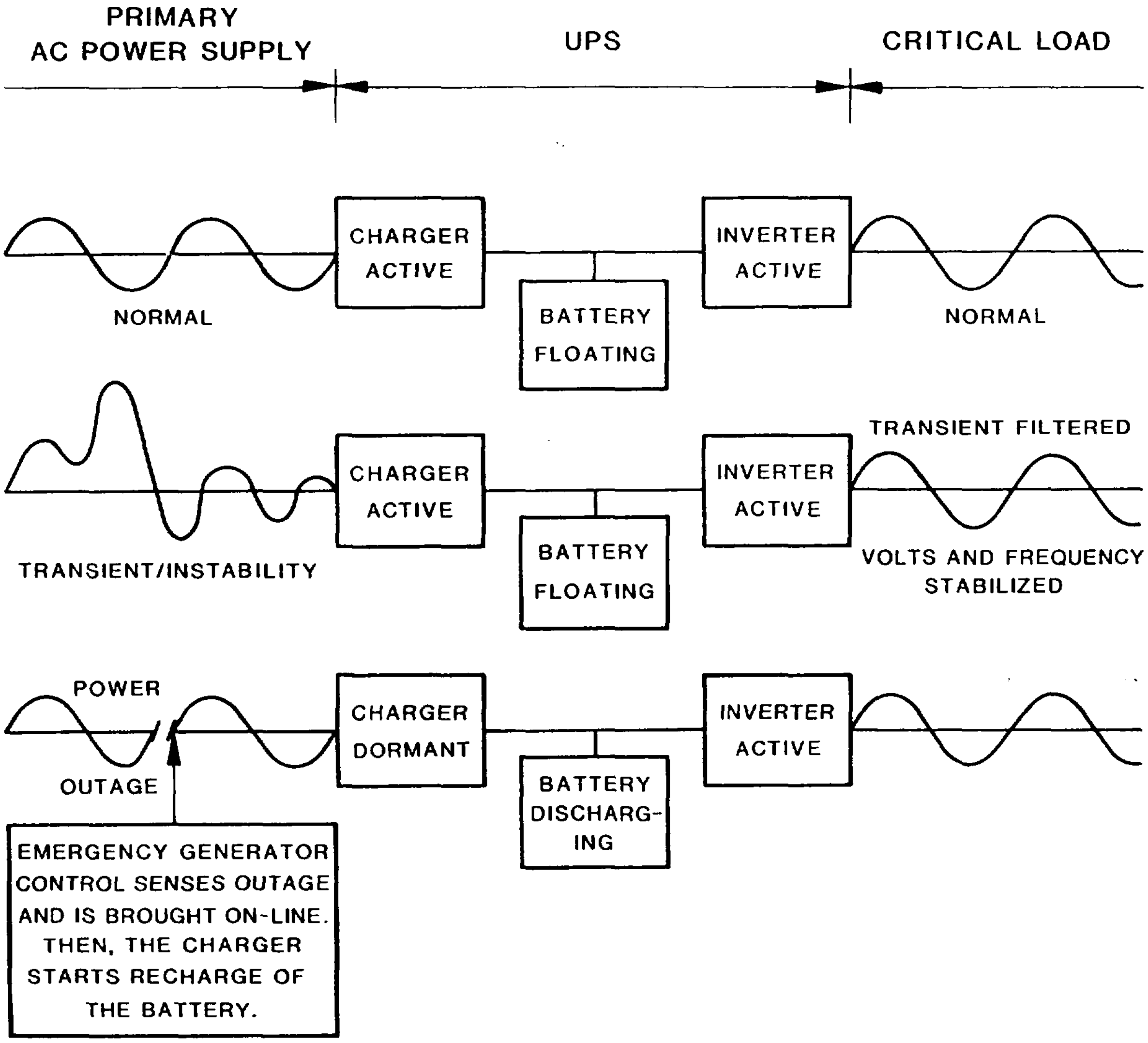


FIGURE 11. Simlpex UPS modes of operation.

the reconstructed sine-wave output does not exceed 5-percent total harmonic distortion (THD) and that no single harmonic exceeds three percent. Also, generator sizing should be adequate to accommodate recharging the batteries following outages.

4.5.2.1 Rotary UPS. The rotary UPS typically uses batteries to power a motor-generator that feeds the critical load. This is a lower initial cost combination that provides very clean sine-wave power. However, older versions of the rotary UPS were undesirable due to the level of audible noise produced and the requirement to periodically replace bearings. The newer motor-generator rotary UPS are comparable to solid-state units in performance and reliability, but they are generally larger, heavier, and more costly in sizes less than 1000 kVA. Motor-generators can also be coupled directly to the incoming ac power and use inertia to ride through momentary power interruptions. The output of such an arrangement produces clean, isolated power, if the interruption is only a few cycles in duration. Another variation on the motor-generator concept has an application in transient protection where a dielectric coupling between the motor and generator provides maximum isolation from the commercial power grid. In this particular motor-generator application, the input power can be either ac or dc and, if required, the generator can provide 50-, 60-, or 400-Hz power to the critical load.

4.5.2.2 Solid state UPS. Although sine-wave power generation by rotary machines provides good regulation and sinusoidal wave quality, a sine wave can be produced by a linear oscillator, ferroresonant inverter, stepped square wave generator, electronic switching, or digital synthesis. Early versions of sine wave generators used silicon-controlled rectifiers (SCRS) to switch the DC input (square wave). The SCR method was efficient, but required considerable filtering to eliminate high harmonic content from the produced sine wave. The ferroresonant inverter approach also suffers from excessive harmonic distortion unless extensive filtering is used. There are designs of the ferroresonant inverter that permit standby UPS. In this configuration, utility power normally flows through a power conditioner to the load. When a power failure occurs, a transfer controller switches the load (in less than one millisecond) to a battery-powered dc to ac inverter. As expected, the standby UPS is less expensive than a full-time one, but damage level transients are coupled to the load until a primary power outage is detected. Power isolation, coupled with a standby UPS, could be a viable power system for noncritical computer-based systems. Figure 12 illustrates the standby UPS concept. Most of the full-time, solid-state UPS systems use microprocessor-controlled digital synthesis Pulse-Width Modulation (PWM) to generate ac for the critical load. Figure 13 is a block diagram of a typical simplex, full-time UPS.

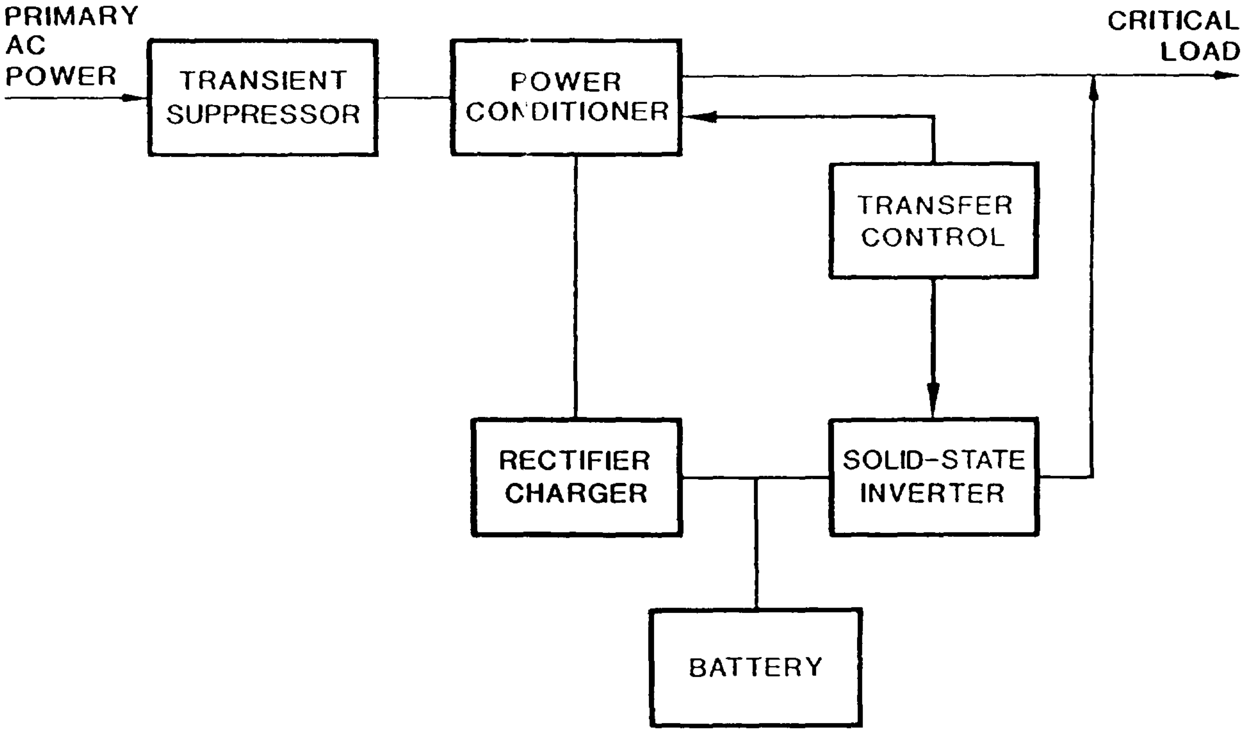


FIGURE 12. Off-line UPS.

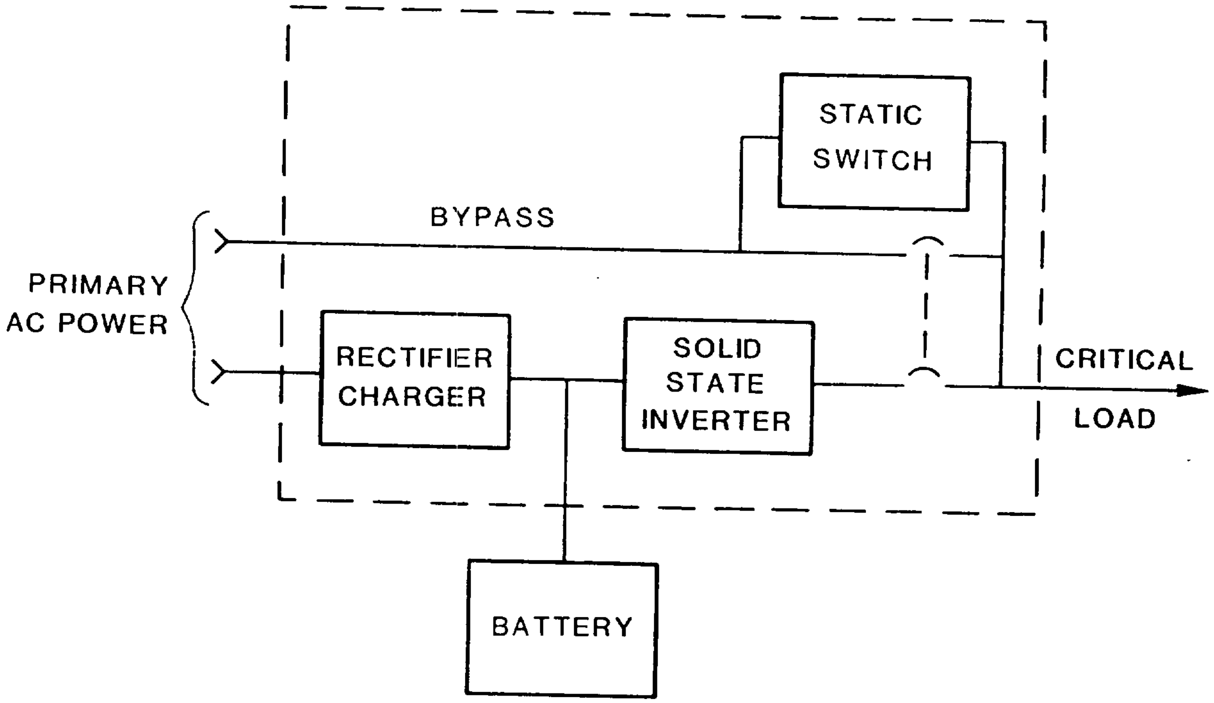


FIGURE 13. Simplex, full-time UPS configuration.

4.5.2.3 No-break generator. The term "no-break generator" refers to a motor generator that is equipped with a heavier flywheel (mechanical energy storage) to ride out momentary power interruptions. Some versions may be encountered that utilize a magnetic clutch to couple an emergency generator to the critical load when a interruption of primary power is detected.

4.5.2.4 UPS bypass. Good engineering practice provides either an automatic or manual UPS bypass. This reconnection to primary ac power is necessary during a complete UPS failure or for maintenance of a simplex UPS (see figure 13).

4.5.3 Voltage regulation. Most manufacturers of conditioned computer power equipment refer to the voltage regulation and transient suppressor stage as the power conditioner. Automatic voltage regulators are available in several different forms. Recent designs have combined solid-state sensing with buck-boost variable transformer circuitry. Ac voltage regulators are relatively inexpensive and efficiencies approach 100 percent. As previously indicated, variable transformers cannot effectively cope with fast-rising transients, but can do an excellent job of regulating ac voltage. In fact, most are capable of regulating input variations of plus or minus 15 percent to plus or minus 0.75 percent on the load side. This means that for a 120-Vac output, a 0.75-percent regulator will maintain an output between 119.1 and 120.9 Vac during input variations between 102 and 138 Vac. Information gathered during the site survey plays an important role in determining if voltage regulation is required for the facility noncritical load. In locations where power brownouts are common and two independent ac power sources are available, subcycle, solid-state transfer switches in combination with voltage regulators will provide an adequate power supply for noncritical computer installations. This configuration also provides an excellent building block on which the remaining elements of an UPS can be added as a critical load develops. The current industry voltage regulation standard for a complete UPS is that the critical load output voltage variation will not exceed plus or minus two percent. This standard is independent of the primary power source quality.

4.5.4 Power isolation. There are several methods to accomplish power isolation (i.e., removal of common mode noise and low-level transients). Some previously mentioned isolation devices include battery-driven inverters and motor generators which absorb most input power irregularities and develop a clean power output. The most conmon approach is to use some form of filtering that passes the 50/60 Hz with very little loss and offers significant opposition to the higher-noise frequencies. In the filter approach, the high-frequency noise content is shunted to ground. The current trend is to use isolation transformers in preference to power filters at the first noise reduction point. This trend is motivated by two factors - first, it is sometimes desirable to change from a delta-connected power source to a wye connection or to change line voltage; and second, filters contain capacitors that tend to puncture when subjected to high-voltage transients. Both isolation transformers and filters are very efficient at the bandpass frequency and, compared to other isolation methods, are inexpensive.

4.5.4.1 Isolation transformers. Isolation transformers act as low-pass filters which pass 50/60-Hz power frequencies efficiently and shunt higher frequencies to ground. This action is a result of special internal shielding which decreases the transformer primary-to-secondary couplin for higher frequencies and offers a high-capacitance path to ground. These transformers also work in reverse, if the connected equipment is a noise generator, by preventing noise feedback into the power grid. Under ideal conditions, isolation transformers have the capability to reduce a 6000-volt noise spike to an insignificiat 0.00015 volt. Isolation transformers are available in single and three-phase versions. Transformers of most kV ratings are available from stock.

4.5.4.2 Power filters. The recent establishment of international EMI/EMC standards for computer-based electronics equipment and the availability of excellent power-conditioning equipment have changed the placement of power filters In general, the power conditioner (see figure 10) has replaced the large power filter at or near the facility power entrance. Physically smaller filters are being used at the shield or chassis level. Although these filters tend to attenuate audible and rf noise in both directions, the main intent of the international standards (see 4.14) is to prevent noise generated by the equipment from being superimposed on both the common and differential mode of the connected power (refer to 4.4). This change has improved overall system reliability because the transient threat to capacitive elements of filters located near the facility power entrance is severe. Filters that are located internal to the power distribution system are basically required to withstand transients that are limited to the conductor/condult acting voltage. Volume II of this handbook contains additional information on filters.

4.5.4.3 Power filter bypass. If, in the interest of protection from HEMP, a facility entrance power filter is specified by the using agency, filter leakage current (a function of line-to-ground capacitance) should be dynamically monitored. This can be accomplished by adapting an adjustable protective relay that will alarm when significant changes in filter element (or insulation) valves occur. To prevent excessive downtime during testing or replacement, a mechanical bypass of large-facility power-entrance filters should be included in the initial design.

4.6 Power distribution. The local utility usually installs pole- or pad-mounted transformer(s) to reduce transmission line voltage to the level required by the customers. High-voltage switches and breakers that the power company installs and controls are located with or near this transformer. utility company traditionally installs overhead or underground service to the building and connects to customer-provided switchgear. This portion of facility power distribution installed by the utility company is called the service entrance. Most small-to-medium-size facilities in the United States will be furnished a wye-connected, three-phase, 277/480-Vac system as illustrated in figure 14. This combination permits the use of smaller wire for a given demand. A neutral (grounded conductor) is provided to handle phase current imbalances. Recent studies by an association of computer and business equipment manufacturers of wye-connected systems have revealed significant odd-harmonic power content on the neutral conductor. of these findings, it is now recommended that the neutral conductor be sized to carry at least 1.732 times the phase current. From the customer-provided switchgear, distribution to other power centers is by feeders. In the case where 120-Vac single phase is required for branch circuits, dry-type transformers are used to reduce the voltage. The one-line power diagram is the first step in determining location of power distribution centers, transformers, breakers, and other protective devices. Dc power distribution also requires careful planning and engineering. In dc systems, inadequately sized conductors and improper connections can result in unacceptable voltage drop or poor power supply regulation. Ac and dc power distribution schemes, such as simple radial, mixed radial and parallel, primary selective, primary loop, are covered in volume II of this handbook.

4.6.1 Circuit breakers and distribution panels. The common designations for ac distribution equipment are listed in table IV. The location of medium-to-large motor control centers (MCCs) and other switchgear must be carefully planned so that the equipment stays dry and has adequate ventilation. The current version of the NEC should be consulted for information on breaker and wire sizes, as well as the location of distribution panels. Methods used for selection and coordination of protective devices are discussed in volume II of this handbook.

4.6.2 Special application for fuses. In a facility that must be capable of quickly returning to operation following a major equipment fault (short circuit), fuses should be considered in combination with breakers as insurance against breaker failure. Fuses are readily available for almost any application; therefore, custom-designed fuses should be avoided because spare supply may be limited to a single manufacturer. The basic types of fuses, characterized by reaction time, interruption rating, and current limiting property are designated as standard, time delay, current limiting, and dual element. The Underwriters Laboratories (UL) has developed basic performance and physical specifications for fuses. The most used of the UL standard classes (under 600 V) are RK 1, RK 5, G, L, T, J, H, and CC.

4.6.3 Ground-fault circuit interrupters (GFCI). The personnel safety aspects of GFCI protection were discussed in 4.4.4. GFCI devices installed on 120-Vac circuits continuously compare the current in the ungrounded phase conductor with neutral. In a 240-Vac circuit, the same principle is used except the comparison is made between two-phase conductors, or the phase conductors and neutral. In 120-Vac circuits, if the current is less than in the phase conductor, a ground-fault exists because a portion of the supply current is returning by a path other than the neutral. In 120/240-Vac circuits, a ground fault exists when the sum of the currents in all three conductors does not equal zero. A current imbalance as low as five milliamperes on UL Class A GFCIS will interrupt the circuit. (The problem discussed in 4.6 on odd-harmonic current content on the neutral also impacts on selection and use of these GFCIS.) Ground-fault breakers are also

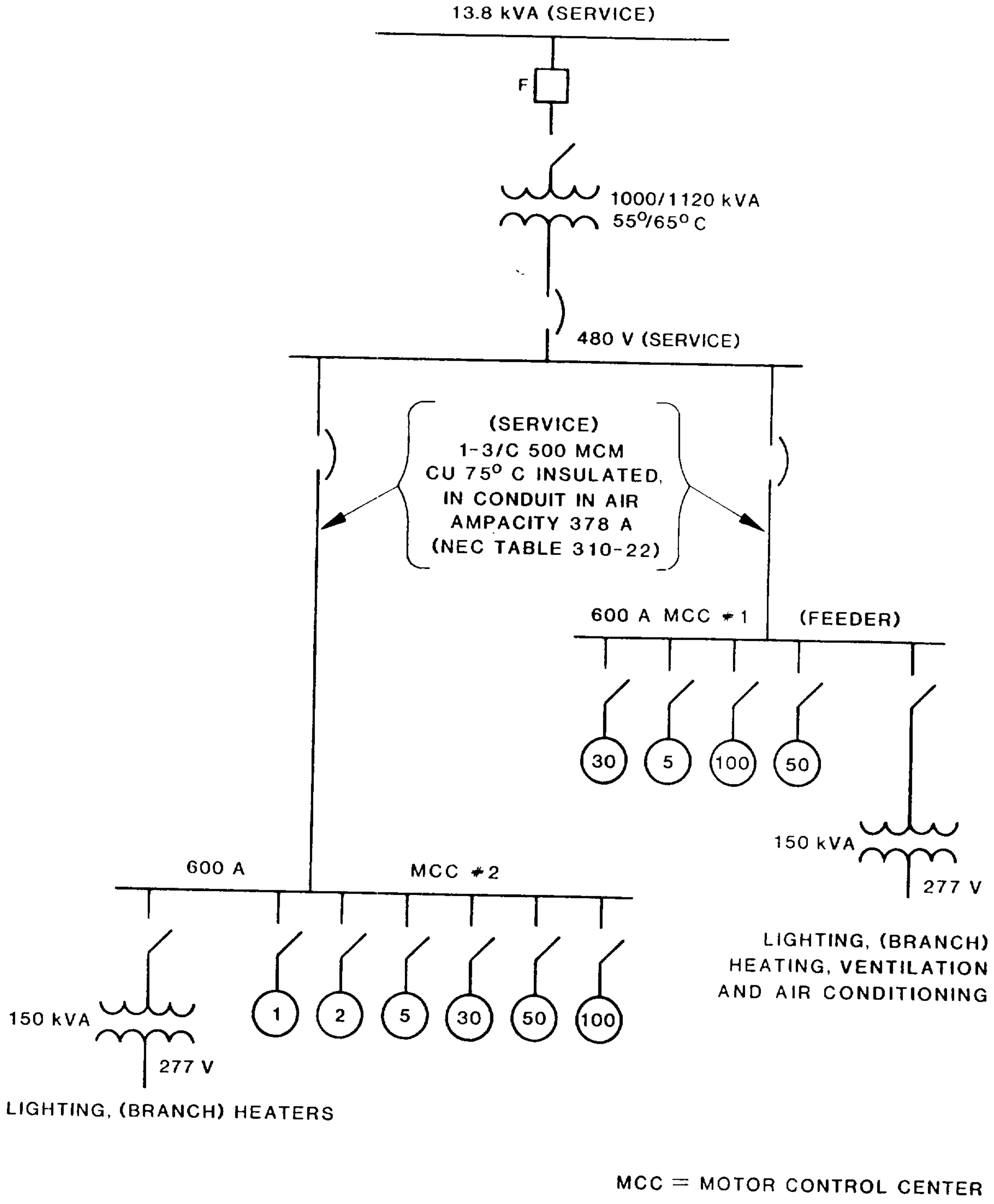


FIGURE 14. Representative ac power distribution diagram.

TABLE IV. Commonly Specified power Distribution Centers.

Equipment designation	Functional description
Switchgear-breakers	Utility provided high-voltage distribution and overcurrent protection (vacuum or oil breakers)
Unit substation	Utility provided high-voltage disconnect switch and voltage reduction transformer with low-voltage magnetic breakers
Motor control center (MCC)	Customer provided large cabinet houses motor starters, molded-case circuit breakers, etc.
Switchboard	Customer provided free-standing cabinet houses overcurrent protectors to motor controllers and miscellaneous power circuits in building
Panelboard	Customer provided wall cabinet for low-voltage distribution to lighting and receptacles also provides overcurrent protection with molded type circuit breaker

available for panelboard installation as the main or branch circuit breaker (75- TO 3000-amp continuous rating. Panelboard ground-fault breakers are usually adjustable for trip current and interruption time.

> NOTE: This type of breaker should be considered for use in repair shop and similar activities where personnel safety is paramount.

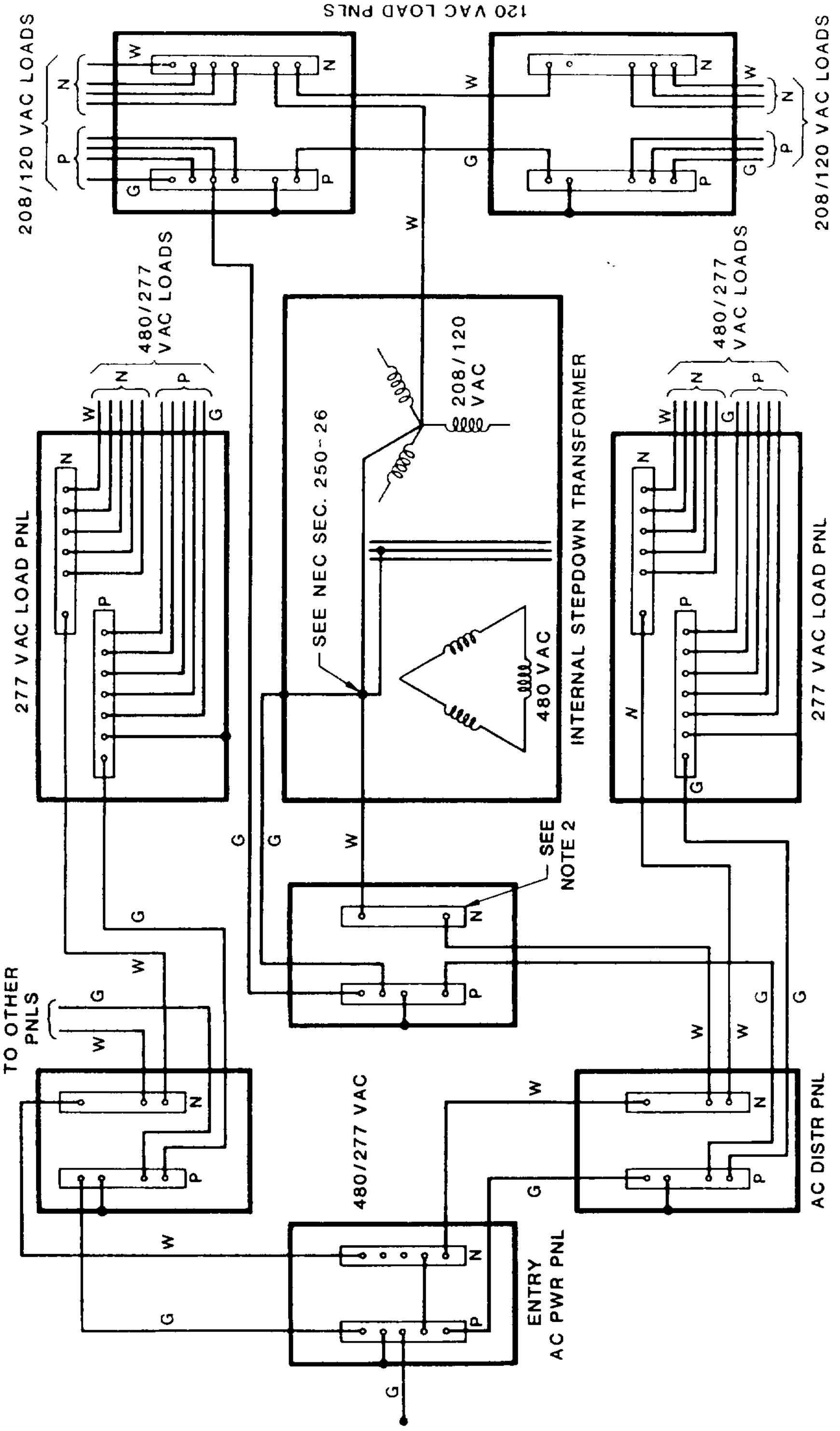
4.6.4 Distribution transformers.

> CAUTION: THE USE OF AN OPEN-DELTA-CONNECTED TRANSFORMER (SEE FIGURE 3) IN SECONDARY POWER DISTRIBUTION-MUST BE AVOIDED. THE OPEN DELTA CONFIGURATION OFFERS IS ONLY TWO TRANSFORMERS ARE REQUIRED POWER).

A closed-delta secondary is also a poor choice compared to a wye connection. This reasoning is based on personnel safety (higher voltages to ground), poorer voltage regulation. and more difficultv in suppressing transients. Delta-connected secondaries do offer slightly higher electrical efficiency and better reduction of some utility-generated harmonics. In transformer selection, the method of cooling and type of winding insulation used are major factors. Cooling methods fall into three classifications: liquid, ventilated, or sealed. Because dry-type transformers are air-cooled, nonexplosive, and nonflanwnable, they are ideal for indoor use. The limitation on dry-type transformers is their basic insulation level (BIL), but winding insulations have been considerably improved in the past few years and the application of transient arresters improves reliability. Where the facility is required to survive the effects of EMP, the highest available BIL rating should be considered. The planner should ensure that transformers selected have sufficient reserve to allow normal facility expansion. Transformer selection and protection techniques are discussed in volume II of this handbook.

4.6.5 Electric motor control and protection. Electric motors must be protected against loss of a phase, phase reversal and transients. Details on methods of protection are in volume II.

4.7 Power system grounding. The NEC should be consulted for specific guidance on power system grounding. The IEEE has also published a “Green Book” on recommended practices for power system grounding and an “Orange Book” on grounding emergency and standby power systems. MIL-HDBK-419 covers the additional requirements for grounding of DoD facilities. This handbook describes an equipotential plane concept that integrates facility power and electronic equipment ground systems. Figure 15 summarizes the fault protection and neutral wiring for a typical facility.



N	AC NEUTRAL BUS
P	FAULT PROTECTIVE BUS
W	WHITE (NEUTRAL CONDUCTOR)
G	GREEN (PROTECTIVE CONDUCTOR)

NOTES:

1. FOR CLARITY, 3-PHASE WIRES, FUSES, SWITCHES, AND CIRCUIT BREAKERS ARE NOT SHOWN
2. FOR SEPARATELY DERIVED SYSTEMS (NEC SECTION 250-26) THE NEUTRAL WILL BE CONNECTED TO GROUND AT A POINT NEAR THE INTERNAL STEPDOWN TRANSFORMER

FIGURE 15. Grounding and neutral wiring.

4.8 Power system monitoring and control. as mentioned in 4.4, portable power system monitors are required during the site survey phase for DoD facilities and a full-time power monitor is required for operational facilities. In addition to gathering data on powergrid reliability, records generated by the facility power monitor can be used to correlate power system disturbances with unexplained malfunctions of computer-based electronics equipment. Power system control is the reaction to load and distribution changes during normal and stressed operations. These reactions range from fully automated, such as the starting and transfer of emergency generators to carryin the system load during power failures, to manual bypass of a power filter for maintenance, testing, or replacement.

4.8.1 Transfer switching. At the facility ower entrance, incoming ac power is segregated into technical and nontechnical loads by use of automatic and manual transfer switches (refer to figure 5).
installed in switchboard cabinets or, on smaller systems, fully integrated with the auxiliary power source. It should be noted that unless transfer switches are equipped with a bypass they cannot be repaired or replaced without causing an outage to the technical load. Switching between dual commercial power entrances, or from commercial to a standby generator, can be by automatic or manual means, depending on the critical nature of the load.

4.8.2 Automatic transfer switches. When a primary power interruption is detected, automatic transfer switche start an emergency power source and then transfer their load circuits to the auxiliary power. When the normal supply is restored and is stable, the transfer switches automatically retransfer their load circuits to the normal supply. Figure 16 illustrates the use of an automatic transfer switch to provide emergency power. To avoid extended downtime during maintenance or repairs, all automatic transfer switches serving critical loads should have a manual bypass included in the original design. Information on paralleling auxiliary power units is in volume II of this handbook.

4.9 Auxiliary power systems. The auxiliary power system is provided to furnish power for operation during interruption or extended degradation of primary power. All auxiliary power systems should be designed for the load requirements developed by using the sample DoD power consumption data collection sheet included in appendix A. For power stability, they should operate near rated capacity (approximately 80 percent).

4.9.1 Engine generators. The major component of an engine generator set is the single- or multiple-phase ac generator (or alternator). Ac power is produced by a generator coupled to a fossil-fueled engine or turbine. A basic qenerator is made up of three parts: exciter, alternator, and voltage regulator. The two types-of ac generators, based on the coupling between the exciter and the alternator, are the rotating-armature (brush) type and the rotating-field (brushless) type. The advantage of the rotating-field type is that the armature winding is stationary and can be connected directly to the load without the arcing and electrical noise associated with brushes. Most small engine generators used in the emergency power role are capable of being locally connected for a wye or delta output and for some variation in voltage level.

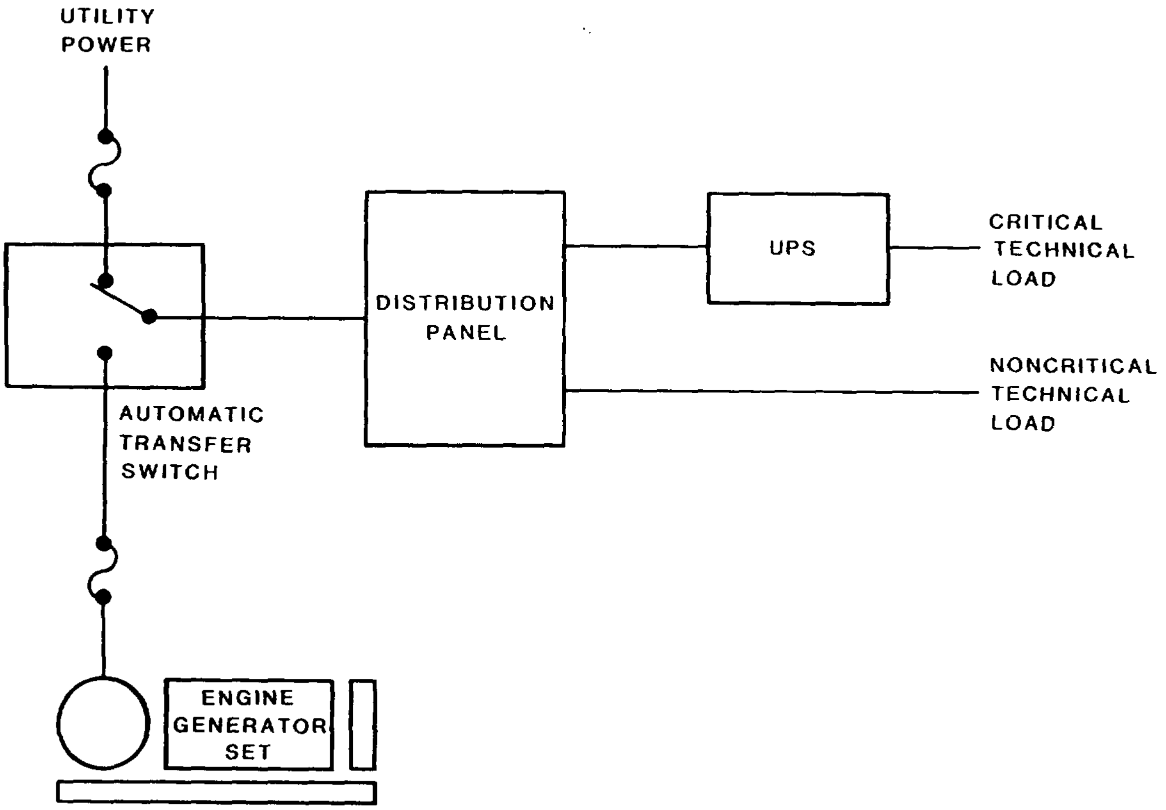


FIGURE 16. Emergency generator transfer switch.

4.9.2 Motor generator. Motor generator sets use an electric motor to drive the generator. They more versatile than engine generators or transformers, because they can be configured to change from ac to dc (or vice-versa) or change frequency of the power supplied to the load. They can ride through most momentary power perturbations, but they do have maintenance and noise limitations. From the cost standpoint, it is estimated that a good, brushless, motor generator can accomplish 90 percent of what a single UPS does at 25 percent of the initial cost. Motor generator sets typically are 19 percent less efficient than a solid-state UPS system, but at current electric rates this is insignificant when compared with the initial cost. They are also available with power failure alarms that can be coupled to a computer system to provide an orderly shutdown.

4.9.3 Integration of auxiliary power systems. The development and maintenance of a facility power hierarchy as described in 4.3.2 is vital to the concept of "load-shedding." A load-shedding plan is required so that noncritical and nonessential loads can be automatically disconnected when the power source is limited for any reason. If on-site generators and commercial power are both on line (parallel), then load-shedding should not be necessary. In the case where on-site generators are in parallel and supplying all power and a unit fails, automatic load reduction is required to match the generator output until other power sources can be brought on line. As critical systems expand, and the demand for auxiliary power approaches the capacity of the installed units(s), a resurvey of facilities should be made to determine if some of the systems that are presently on auxiliary power are no longer mission critical (refer to 4.2.9). Following this survey, if expansion is still required, age and maintainability considerations determine whether existing auxiliary power equipment must be replaced with larger equipment or paralleled with compatible units. Information on paralleling auxiliary power units is in volume II of this handbook.

4.9.4 Location.The two major considerations when locating an auxiliary power system are noise and fumes. The noise consideration pertains primarily to motor (rotary UPS) and engine-driven generators. For further information on noise, consult individual service manuals such as NAVFAC DM 3-14, Power Plant Acoustics. Some versions of solid-state UPS must be in an environmentally controlled room. All auxiliary power systems should be located in an area that is relatively dust free. Fume control is a problem with any large battery bank such as used with a static UPS. Additional planning information for battery rooms is in 4.11.2.2. The battery bank for an UPS must be very close to the static UPS to keep dc voltage drop to a minimum. Fumes can also be a problem if the engine generator exhaust is not adequately separated from the building outside air inlet.

4.9.5 Fuel types and storage. The fuels most commonly used to power facility electric-generating plants are natural gas, liquified petroleum gas (LPG), gasoline, and diesel. Of these, the only fuel not considered suitable for critical DoD facilities is natural gas. Natural gas is considered an interruptible fuel source. The only instance where it might be used is in an area where natural gas is plentiful and a dual fuel engine is specified. This type of engine can be switched from natural gas to stored diesel with a simple valve action. It is very important to consider the Btu content of a planned fuel supply and the effect this has on engine horsepower. Engines must be derated for low Btu content fuels and for operation at high altitude. Engine output at high altitude can usually be maintained by turbocharging. LPG tends to be more vulnerable under stress conditions due to its above-ground storage requirements. Gasoline can be stored underground, but has limited storage life when compared to diesel fuel. When availability, Btu content, and storage are considered, diesel is the preferred fuel for emergency or standby generators. Most emergency generators use No. 2 diesel fuel, which can also be used for building heat and can utilize the same storage facility. The main fuel tanks must not be within the building, but should be placed underground, or within protective enclosures. Diesel-fueled units will normally require a small day or transfer tank near the engine to ensure quick starting. Buried, doublewall, fiberglass tanks are rapidly replacing metal fuel storage tanks. These units do not corrode, do not add water to the fuel from condensation, and seldom require maintenance. Care must be taken to place fuel tanks in locations that will not result in gravity flow of spilled fuel to operations, buildings, power plants, or other site components.

4.9.6 Auxiliary power system monitoring and control. Since the function of auxiliary power units must be carefully scrutinized to determine not only reliability, but output quality. For example, sine wave purity from any type of ac power conversion or isolation system is very important, as is the level of harmonic content. Voltage and speed regulation of engine and motor generators is critical to proper equipment operation. Automatic load transfer switches must use high-quality components and be invulnerable to grid disturbances which could damage on-line power status sensing devices. Switching dc power supplies must meet EMI/EMC standards for the deployed geographical area, as well as the ripple output tolerance of connected equipment.

4.9.7 Auxdiliary power system monitoring and control. Since the function of auxiliary power is to provide power for operation during extended degradation or interruption of primary power, the system must include monitoring and controlcapabilities. Minimal engine (prime-mover) control functions are: remote start/stop, overcrank protection (engine does not start), high engine temperature, low oil pressure, and overspeed. NFPA-76A, generator set alarm package, requires individual alarm lights for the conditions shown in table V. Engine generators can create sags and surges that rival those of the commercial power network, so an UPS will still be required for critical loads. The output voltage regulation design goal for emergency generators below 20 kW is in the +5-percent range and above 20kW is in the +2-percent Other desirabl~ control and monitor features are: volta~e adjustment rheostat, engine test switch with automatic and manual start/stop positions, engine meter kit, switchable ac meter kit, and alarm horn/silencing switch.

TABLE V. NFPA-76A Alarm Light Recommendations for Engine Generators.

Low engine coolant temperature (heater not functioning)
High engine temperature prealarm (approaching shut-down)
Unit shut-down due to high engine temperature
Low oil pressure prealarm (approaching shut-down)
Unit shut-down due to low oil pressure
Unit shut-down due to overcrank (engine fails to Start)
Unit shut-down due to overspeed (line frequency rise)
Indication of battery charger malfunction
Indication of low fuel in main tank
System ready indication

4.9.8 Energy conservation methods. Even carefully designed DoD facilities waste appreciable amounts of energy. Waste gases and discharged liquids from buildings contain a considerable amount of energy that, in most cases, can be economically recovered. Sources of waste heat are: engine exhausts, fume hoods or ventilation fans that are not equipped with heat exchangers, and building wastewater. Energy conservation through improved insulation, lighting, and HVAC systems is discussed in 4.13.7 of this handbook. Power-generation equipment energy conservation methods center on exhaust and cooling fluid heat recovery that can be used for other building functions. It is obvious that recovery is impractical without a use for the recovered heat. Most utility companies charge volume users more when the load exceeds a computed peak. This is known as a “demand charge” and can be user-controlled by automatic or manual load shedding (see 4.9.3). Higher rates per kW are also charged if the facility power factor (refer to 4.2.9.2) is too low. Low efficiency ratings of power conversion equipment can also be a major factor in total power consumption for DoD facilities. Personal computer programs are available to analyze the thermal and economic performance of a planned or existing building. These programs can look at performance for any period of interest and consider such things as local weather conditions, thermal mass, and building operating schedules. Smaller facilities that can take advantage of the alternative power systems discussed in 4.10 can effect the maximum energy savings.

4.9.9 Cogeneration. The concept of cogeneration, the simultaneous extraction of both electrical and thermal energy from a single fuel source, is not new. The advent of efficient packaged systems and recent Government regulations have vastly increased public awareness and interest in cogeneration. Figure 17 illustrates the concept of cogeneration. The Public Utilities Regulatory Policy Act (PURPA) of 1978 permitted cogenerators that have demonstrated compatibility with the power grid to sell excess power to public utilities. The Federal Energy Regulatory Commission (FERC) has now resolved the last stumbling block to installation of cogeneration units by ruling that cogenerators have the right to buy backup power from the utility

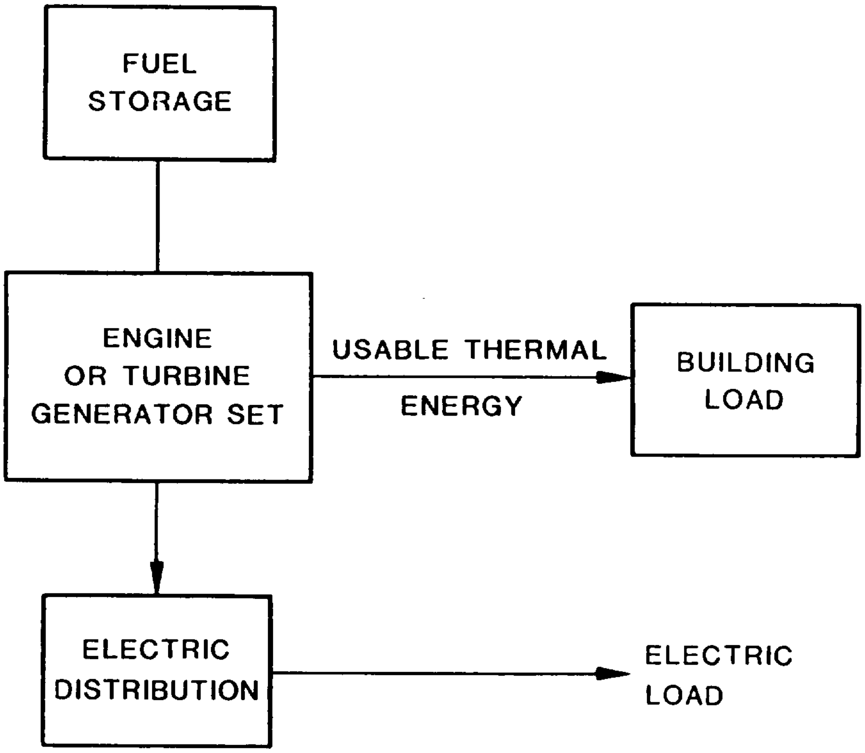


FIGURE 17. Cogeneration concept.

company during peak demand or maintenance schedules. Early packaged cogeneration systems were not highly efficient, but newer versions have fuel efficiencies in the 80-percent range. Packaged units capable of operation on natural gas, LPG, or diesel fuel are available in a wide range of power outputs. Due to their thermal efficiency and quick installation, these units are particularly attractive for new DoD facilities that do not have access to a power grid. The two basic modes of cogeneration are: bottoming cycle, where the input energy is first used in a thermal process and the rejected heat is then used for power production; and the reverse process, which is called topping cycle. Chapter 8 of the ASHRAE HVAC Systems and Applications Handbook presents a detailed dicussion on cogeneration.

4.10 Alternative power sources. Within the DoD, alternative ower sources are defined generally as any source other than fossil fuels. Ongoing research and development efforts are addressing sources such as the sun, renewable alternate fuels, fuel cells, and small nuclear reactors. Hydroelectric power plants, which use water driven turbines to generate electricity, are used by certain commercial or publicly owned companies. Continuing studies address the harnessing of tidal energy in areas where large tidal variations are experienced. Energy extraction methods use turbine generators driven by the ebb and flow of tidal water. Power generation from naturally occuring local resources is very attractive at remote and isolated locations, especially those without access to a commercial grid or which would require fuel to be transported over long distances or under adverse conditions. Storage batteries and flywheels are also regarded as alternative energy sources that are better suited to UPS applications. The use of renewable, alternative power sources at DoD facilities should always be considered for reasons of cost reduction, fuel savings, and environmental impact.

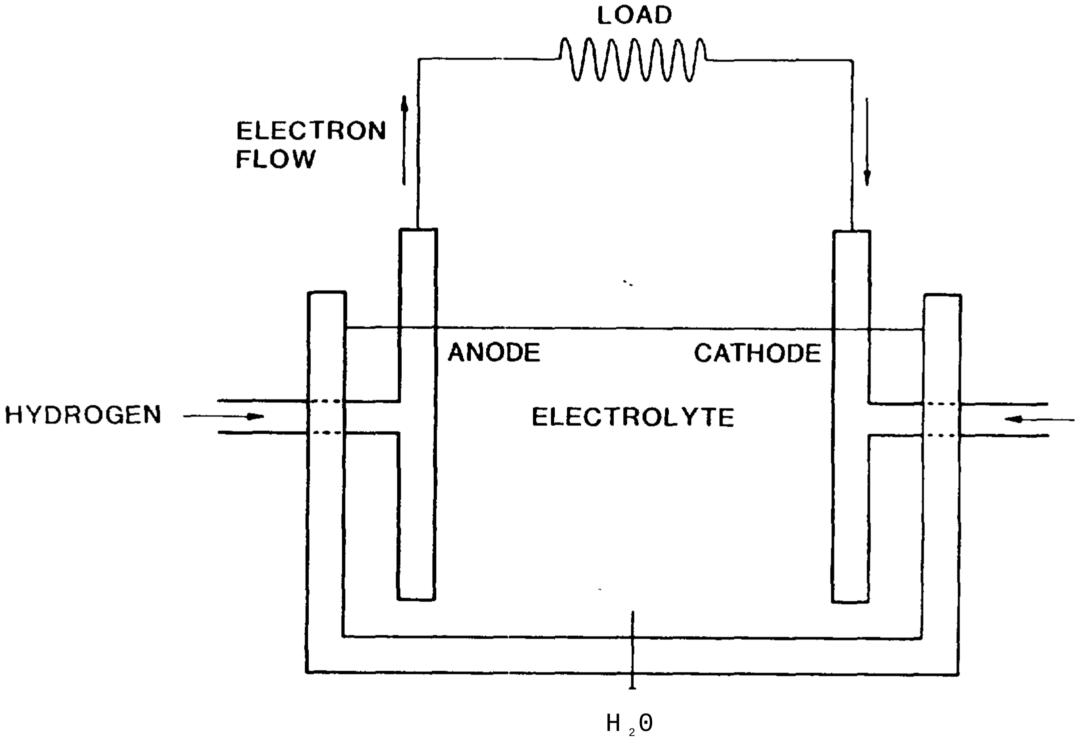
4.10.1 Solar power. Solar energy is inexhaustible, requires no fuel, does not pollute the environment, is available almost everywhere, and cannot be controlled by other nations. Photovoltaic devices (solar cells) are used to enerate electricity for space vehicles and at remote and unattended terrestrial locations. Turbogenerators, currently employing the heat produced by burning coal , oil, and natural gas, can be powered by the sun in a process called solar thermal energy conversion. Similarly, small power requirements are being met through the use of solar heat engines. The availability of solar radiation at a particular location is, of course, the prime consideration for proposed application at a site. The amount of solar energy that the site receives should be included in site survey data. The economical advantages of using the sun as a supplemental energy source for DoD installations should always be considered.

4.10.2 Renewable alternate fuels. A variety of renewable gas, oil, and alcohol-type fuels is being developed by biomass conversion. The U.S. Department of Energy (DoE) defines biomass as “standing vegetation, aquatic crops, forestry and agricultural residues, and animal wastes”. The photosynthesis process produces biomass when green plants convert solar energy, carbon dioxide, and water into carbohydrates. The DoE is sponsoring research into the practical production of fast-growing trees, sugar crops (beet and cane), and other promising herbaceous plants. By-products from agricultural and forestry industries are also sources of biomass. Several processes are used to extract the energy from biomass, either as a fuel product or directly as heat.

4.10.3 Fuel cells. Fuel cells provide electrical power by convertin the chemical energy released in the oxidation of hydrocarbon fuels directly into electrical energy. Fuel cells, which consist of two electrodes separated by an electrolyte, are actually types of primary batteries in which reactants are consumed. Fuel cells are classified according to the type of electrolyte they contain, temperature range in which they operate, and type of fuel they consume. The most prevalent and successful fuel cell applications employ hydrogen and oxygen as the reactants. Figure 18 illustrates the basic operation of a hydrogen/oxygen fuel cell. Fuel cells are very attractive for tactical and mobile applications. They have the advantages over engine-driven generators and conventional batteries of being lighter in weight, smaller in size, less polluting, and essentially noiseless. The disadvantages of current fuel cell technology are high cost and short lifetime.

4.10.4 Wind energy conversion. The basic principle of wind energy conversion is simple. Moving air has kinetic energy due to its mass and velocity. This kinetic energy will move blades or rotors that are mechanically connected to a turbine generator shaft. A variety of blade and rotor shapes, mounted on either horizontal or vertical axes, use aerodynamic lift or drag for movement. Large wind turbine installations are relatively expensive. The use of wind energy as a supplemental source of electrical power should be considered in those geographical areas where site survey data indicate high availability of winds. Small remote sites are good candidates. Composite power plants using wind turbines along with other solar energy applications (solar cell arrays) and storage batteries can provide clean and economical electrical power.

4.10.5 Small nuclear reactors. Major concerns over the use of nuclear reactors are high initial costs, personnel safety, and protection of the environment. Most research efforts to develop small nuclear reactors have been for space applications. With a power production capability from a few hundred watts to several kilowatts, small nuclear reactors are attractive for use at lower power electronic facilities, especially in remote locations. Their potential hazards to personnel and the environment notwithstanding, the clean and quiet operation and long life of nuclear reactors can be seen as advantages, particularly in tactical environments. The technical aspects of nuclear reactors are beyond the scope of this handbook. When R&D efforts produce practical models, small nuclear reactors will likely find application at selected DoD facilities.



AT THE ANODE, HYDROGEN (H) REACTS WITH THE HYDROXYL IONS (OH) OF THE ELECTROLYTE TO FORM WATER AND RELEASE FREE ELECTRONS (E) IN THE FOLLOWING REACTION:

$$H2 + 20\ H- \;-\; 2H_20 + 2E$$

AT THE CATHODE, OXYGEN (0) REACTS WITH WATER AND FREE ELECTRONS (E) TO FORM HYDROXYL IONS IN THE FOLLOWING REACTION:

$$\frac{1}{2}O_2 + H_2O + 2E \longrightarrow 2OH^-$$

FIGURE 18. Hydrogen/oxygen fuel cell.

4.11 Direct current (dc) systems. Dc voltage systems are increasingly being used in Doll facilities to provide power directly to communications equipment at the chassis or rack level, to provide emergency backup power for critical parts of a load UPS, and to charge emergency engine generator starting batteries. Dc UPS units are particularly suited to provide backup power to a computer's memory and register circuits to prevent loss of data during an orderly shutdown following a power failure. Figure 19 illustrates an application of a dc UPS for microcomputer backup power.

4.11.1 Rectifier/chargers. Rectifier/chargers are used to convert ac voltage to dc voltage, and to maintain a constant level of charge for storage batteries. During normal operation, the unit maintains batteries by a low-amperage trickle charge. Following a power outage and restoral of ac power, the charger provides a higher amperage to return the batteries to the fully charged condition. A stand-alone rectifier may also be used to provide dc voltage to a distribution panel for use throughout the facility.

4.11.2 Batteries. A battery consists of a group of cells connected in series to develop the desired voltage, and in parallel to provide the required current. Wet-cell storage batteries are commonly used as an integral part of the dc power system. Batteries used for UPS and computer-based electronics applications generally fall in three major categories:

Wet-cell batteries (lead antimony, lead calcium, and nickel-cadmium).

Maintenance-free batteries (lead-acid and nickel-cadmium).

Nonmaintainable batteries (usually lead-acid).

Wet-cell batteries are characterized by a cell vent and removable cap to permit checking and adjustment of the electrolyte. This type of construction, though simple, has the disadvantage of producing gas bubbles during charge which vent from the cell with a resultant loss of water. Maintenance-free batteries have special seals. While the battery is charged, the seals hold the hydrogen and oxygen produced inside the cell until recombination as water occurs. Nonmaintainable batteries are characterized by an excess of electrolyte which may be gelled or absorbed in the separations to prevent spillage. This type, sometimes referred to as "gel-cell," still vents hydrogen and oxygen when the designed vent opening pressure is exceeded during charging. The main advantage of this type of battery is that it does not leak liquid in normal operation and can be mounted within equipment cabinets. It is also reasonable to consider this type of cell where seismic concerns are a factor. Table VI provides a general comparison of battery types, but due to rapidly advancing battery technology, characteristics of new product lines should be studied before a type decision is made.

4.11.2.1 Sizing. Sizing of battery systems is discussed in volume II of this handbook .

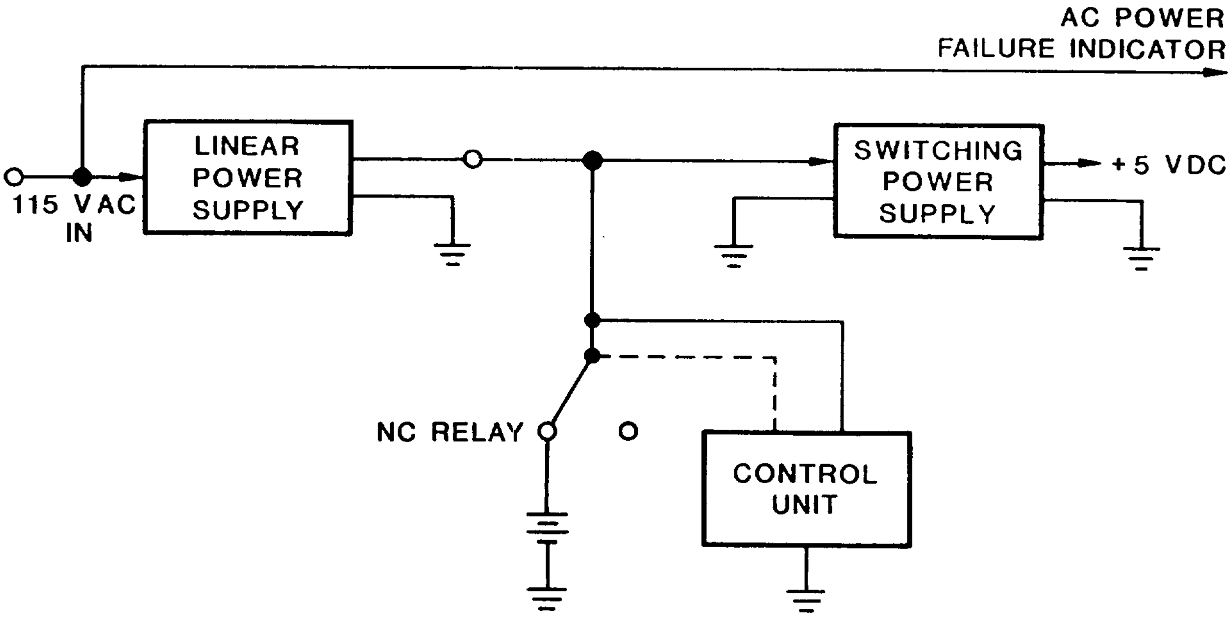


Figure 19. Small dc UPS for microcomputer.

4.11.2.2 Battery room considerations.

> CAUTION: TO PREVENT CORROSIVE FUMES IN PERSONNEL ARERAS, THE BATTER Y ROOM SHOULD BE ISOLATED FROM THE OPERATIONS AREA. (See 4.11 .3)

The station service and UPS batteries should normally be in separate rooms. The UPS battery room should be adjacent to the UPS equipment and the station battery room should be centrally located in relation to equipment loads to reduce wire losses. The room should be constructed of noncorroding material. Air intake and exhaust fans, sized as necessary, should be installed to provide adequate removal of acid fumes (see 4.11.2.2.4). The room should be free of windows or other apertures that allow sunlight to influence the temperature of the cells. It is desirable for all cells to remain at the same temperature. A drain should be installed in the floor for the shower and eye-wash basin. If no drain is provided, a catch basin or tub should be constructed around the battery racks. This arrangement will contain any overflow, although it will not dispose of it. Neutralizer should always be available in the battery room to treat minor spills or leaks of electrolyte.

4.11.2.2.1 Weight. Methods to estimate weight of battery systems are found in volume II of this handbook.

4.11.2.2.2 Racks. Battery racks should be designed and installed to support the weight of the required batteries. Racks should be appropriately finished to resist acid corrosion.

4.11.2.2.3 Seismic concerns. The design of battery racks should be compatible with the seismic environment in which they are located. In regions where seismic activity is likely, special attention must be given to rack construction. Heavier, securely braced racks are necessary in these locations. The type of battery selected should be based on the resistance to acid spill (refer to 4.11.2).

4.11.2.2.4 Ventilation/hazardous gas control. The battery room should be continuously ventilated with dual fans. Air intake and exhaust for the battery room should be at a rate that ensures the hydrogen concentration remains below 2 percent. In addition, "no smoking" signs should be prominently posted in the battery room and on the door.

4.11.3 Battery safety. It is unlikely that DoD battery rooms will have sufficient hydroyen concentrations to warrant a classification requiring special protection under the NEC (NFPA). However, as a safety matter, projected hydrogen levels should be checked during the design stage to verify the room is "intrinsically safe". Consideration should be given to the use of acid-resistant lighting fixtures in each battery room to improve life and reliability of the fixture. Portable fire extinguishers should be provided in and adjacent to the battery room. Each battery room should have a fire detection and an automatic suppression system.

TABLE VI. Characteristics of Battery types.

Battery type	Life expectancy (years)	Replacement* cost	Produce hydrogen gas when overcharged	Reconditioning** recharge required
Vented cell lead-acid antimony	10-20	Low	Yes	No
Vented Cell lead-acid calcium***	15-20	Medium	Yes	No
Vented cell Nickel cadmium	15-20	high	Yes	Yes
Sealed Lead-Acid Gelled electrolyte	3-5	High	Yes	No
Sealed lead-acid wet-cell	3-8	Medium	Yes	No
Sealed nickel cadmium	10-15	High	Yes	Possibly depending on usage

* Costs are based on cost data of various manufacturers.

** Nickel-cadmium batteries generally require less water addition than lead-acid batteries, but the need for periodic deep discharges and reconditioning charges tend to offset this advantage.

*** Due to the lower deterioration of lead-calcium cell plates as compared to lead-antimony cell plates, the production and emission of hydrogen gas is lower in the lead-calcium cells.

SOURCE: Specifying Engineer, October 1976.

> NOTE: The battery room should be equipped with a water source in case of accidental exposure to acid. An eye wash basin and an emergency shower are recommended. Protective gear should be provided for battery servicing and maintenance (e.g., rubber gloves, aprons, and goggles. Where tools are provided for battery maintenance, the tools should be insulated.

4.11.4 Overvoltage protection for direct current (dc) sources. Overvoltage and overcurrent protection for dc distribution is accomplished using fuses, circuit breakers; and protective relays. The methods for dc protection closely parallel those for ac including the application of transient protectors. Temperature sensitive resistors (polymers) that are available for low voltage (40 volts or less) ac and dc applications offer the advantages of small size, remote resetting, and are used over hundreds of switching cycles. There are also dc UPS available to selectively provide backup for critical memory and register circuits during power outages. Refer to figure 19.

4.12 Power system upgrade planning. As mentioned in 4.9, emergency generators must be operated near their rated capacity to be efficient and stable. This also implies that as facility emergency power demands increase by a few percentage points, the capability must exist to either replace engine generators with higher capacity units or add parallel operating units. In either of the upgrades options, the initial design of the structure housing the emergency generators must include additional floor space for expansion or the building must be open ended to permit logical expansion by extension or to permit access for generator removal or replacement.

4.13 Environmental considerations. A DoD communications or data processing facility should be provided with environmental control systems that fully support the reliable, survivable, and economical operation of mission equipment, as well as the comfort and safety of personnel. While the configuration of mission equipment may be standardized, the building housing the mission equipment and the supporting environmental systems should be designed according to local climatic and geographical conditions. All pertinent data on local conditions should be gathered during the site survey. Accurate and thorough site survey data will provide the basis for the best choice of architectural design, construction materials, heating, ventilating, and air-conditioning (HVAC) equipment, and other environmental devices. Wherever possible, without jeopardizing mission performance, energy conservation, and protection of the environment should be incorporated into the facility design.

4.13.1 Fundamentals of environmental control. This section contains basic definitions and terminology used in the construction and HVAC industries. They are provided to facilitate understanding of the text of this volume.

4.13.1.1 Temperature. The temperature measured with an ordinary thermometer is calTed the dry-bulb temperature (DBT). This term is used to differentiate it from the wet-bulb temperature (WBT), which relates to humidity levels (amount of water vapor) in the air. Wet-bulb temperature is the temperature measured by a thermometer with a wetted bulb that is exposed to a stream of air. The stream of air passing over the wetted bulb causes evaporative cooling and a temperature reading lower than that from a dry-bulb thermometer. A sling psychrometer, shown in figure 20, measures both temperatures simultaneously. The dew-point temperature is the level at which the air is saturated (100 percent) with water vapor.

4.13.1.2 Humidity. Humidity refers to the amount of water vapor present in the air. Relative humidity is defined as the ratio of the partial pressure or density of the water vapor in air to the saturation pressure or density, respectively, at the same dry-bulb temperature and barometric pressure. If the relative humidity is 45 percent, the air is 45 percent saturated with water vapor. Humidity is measured by instruments called hygrometers. State-of-the-art hygrometers, which contain materials that change electrical characteristics as the humidity varies, are being used increasingly for control of humidity in critical areas such as computer rooms. The humidity ratio (also called specific humidity) is the weight or mass ratio of water vapor to dry air in the atmospheric air/water vapor mixture. It may be expressed as pounds of water vapor per pounds of dry air or grains (gr) of water vapor per pound of dry air. One pound equals 7000 grains (1 gr = 0.0648 grams). Other important HVAC terms, concerned primarily with dehumidification, are defined as follows:

a. Dehumidification is the process of removing water vapor from air.

b. Dehydration or drying is the process of removing water from any substance.

c. Sorption is the process of taking and holding a substance by either absorption or adsorption.

d. Absorption is the process of extracting one or more substances from a fluid (air or liquid) by the holding action of a special material called an absorbent.

e. Adsorption is the process of extracting one or more substances from a fluid by the adherence of those substances to the surface of a special material called an adsorbent.

4.13.1.3 Atmospheric air. The condition of the atmospheric air is defined by the following terms:

Air quality refers to the chemical composition of the atmospheric air. The quality of the indoor air in the work place is important to personal comfort and health. See 4.13.1.6.

b. Air cleanliness refers to the amount of filterable particulate matter such as dust in the air.

c. Air circulation refers to the controlled movement of air within a building.

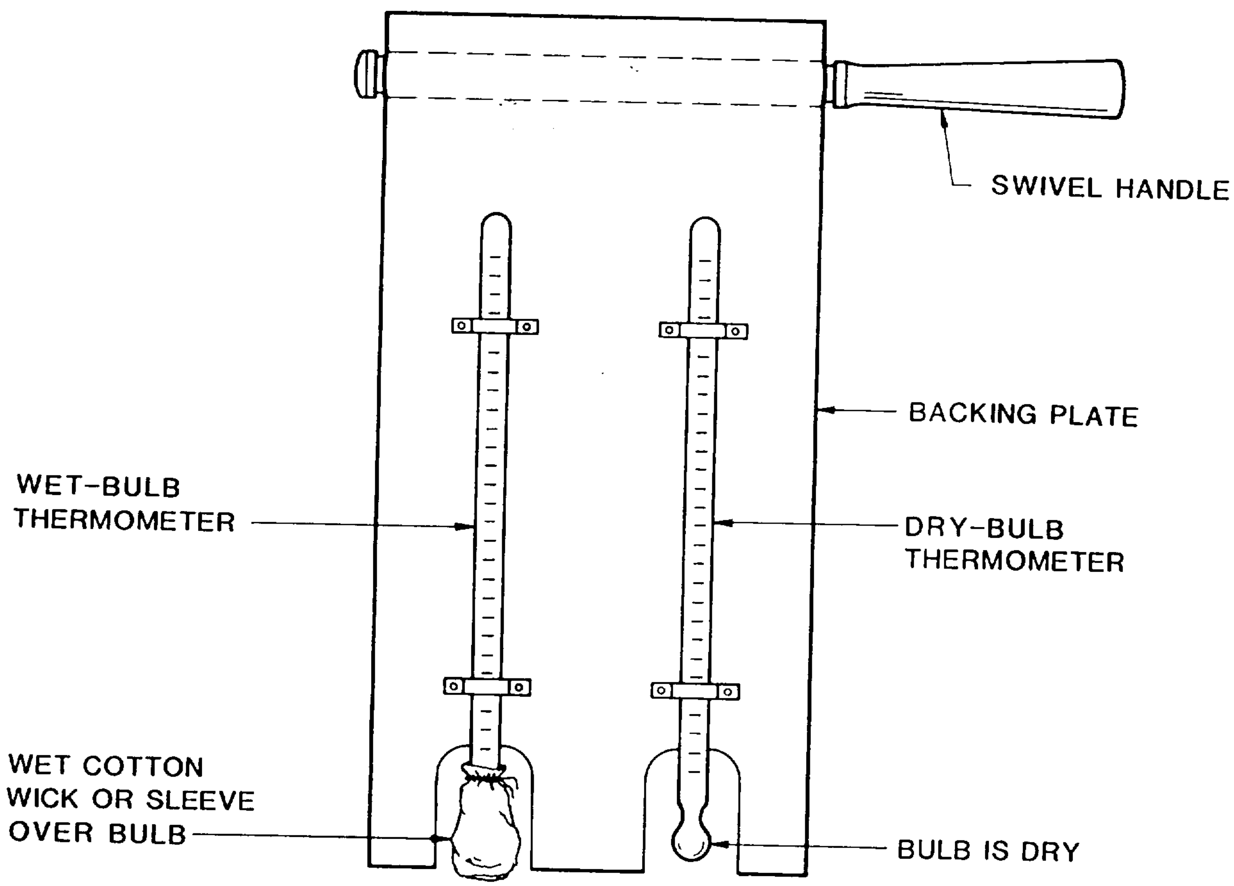


FIGURE 20. Sling psychrometer.

4.13.1.4 Pressure. Fluid (air, water, and refrigerants) pressures are important parameters in the control of environmental systems. Air pressures in ductwork are measured by devices called manometers, as shown in figure 21. The basic pressure required to overcome the resistance to the flow of air that is inherent within the ductwork is called static pressure. This resistance is caused by friction of the inner duct surfaces, bends in the ductwork, and the action of vanes, dampers, and similar devices. Velocity pressure is a manifestation of the rate of air movement. Total pressure is the sum of static and velocity pressures. The flow of liquids is also expressed in terms of static and velocity pressures. The weight of liquids in vertical pipes, especially water, must also be accounted for. This element of the total pressure is called elevation pressure. Fluid pressures are commonly defined by a linear unit called head. This measurement represents the equivalent weight of a vertical column of water that the pressure would support. Head is usually expressed in feet.

4.13.1.5 Psychrometrics and the psychrometric chart. Measuring and applying the thermodynamic properties of moist air is called psychometrics. Psychometric charts are a graphical representation of these properties. Figure 22 is an example of a psychometric chart, showing how the seven thermodynamic properties of moist air are determined. ASHRAE has developed five of these charts to cover various altitude (pressure) and temperature ranges.

4.13.1.6 Personal comfort and health. In addition to maintaining the design environmental conditions require mission equipment, HVAC systems must provide for the comfort and health of personnel.

4.13.1.6.1 Indoor air quality (IAQ) and pollution control. Improved building construction and efforts to reduce energy consumption create the potential for poor indoor air quality. Increased-pollutants, especially carbon monoxide and carbon dioxide, are the cause of a phenomenon called the sick building syndrome. A multitude of studies have shown that as indoor air quality is reduced, complaints of discomfort and illness by building occupants increase. In addition to the obvious problems from tobacco smoke, construction dust, and harmful chemicals given off (outgassed) by construction materials and furnishings, poor maintenance of HVAC equipment can cause growth of biological contaminants. Table VII lists the major indoor pollutants and their effects. Indoor air quality should be monitored to ensure standards are being maintained.

a. Indoor air quality is monitored by devices that employ electromechanical , electrochemical , pellister (photosensitive film), or infrared sensors. The quality of indoor air is maintained by filtration of contaminants, exhaust removal of pollution sources, and the introduction of fresh outdoor air, through ventilation systems, to effectively dilute contaminated indoor air.

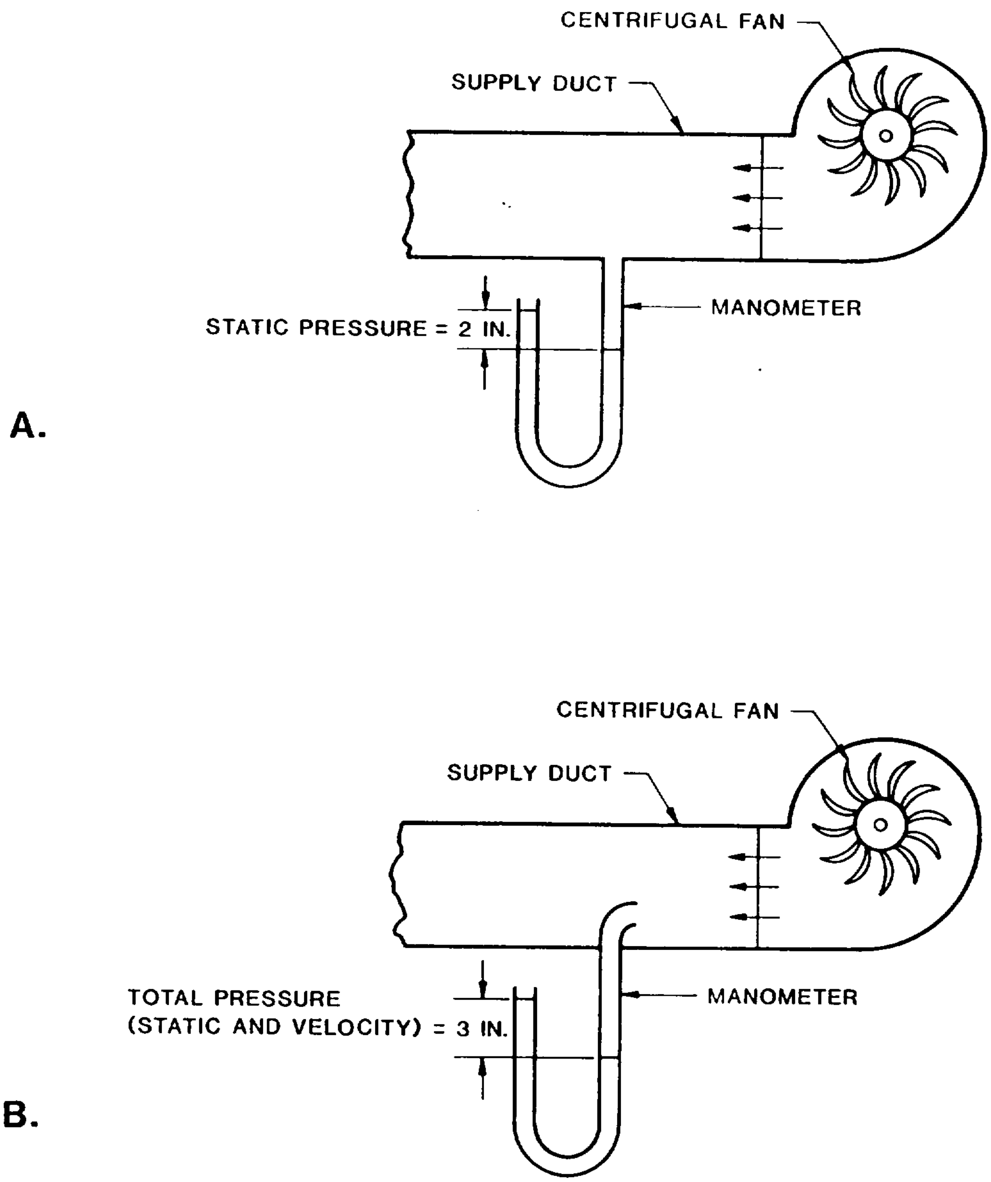
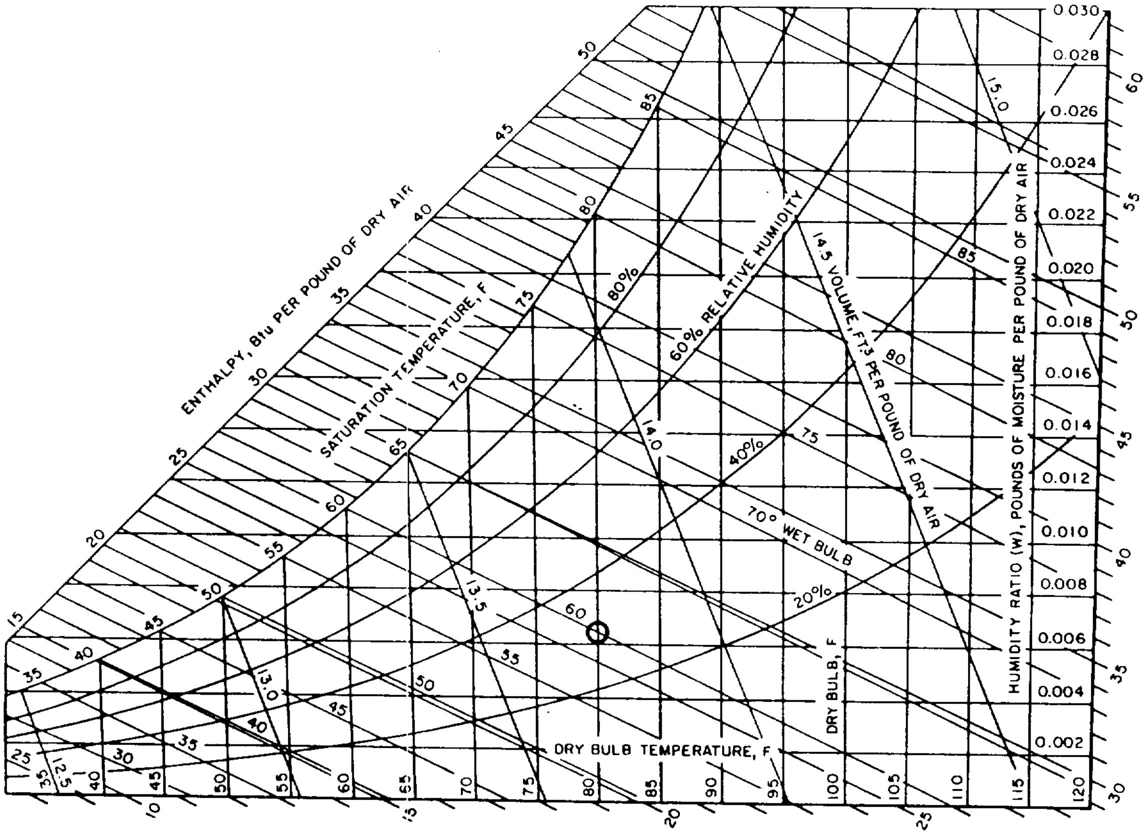


FIGURE 21. Manometer.



HOW MOIST AIR PARAMETERS ARE OBTAINED

ASSUME THAT PSYCHROMETER TEMPERATURES OF 80° F (DBT) AND 60° F (WBT) HAVE BEEN READ. THE STARTING POINT IS THE INTERSECTION OF THE TWO STRAIGHT TEMPERATURE LINES FOR THESE VALUES. (CIRCLED ON CHART)

TO FIND	ACTION
HUMIDITY RATIO (W)	MOVE HORIZONTALLY TO THE RIGHT AND READ 0.0064 FROM W SCALE
RELATIVE HUMIDITY (RH)	INTERPOLATE AND READ 30% BETWEEN THE 20% AND 40% RELATIVE HUMIDITY CURVES
SPECIFIC VOLUME (SP VOL)	INTERPOLATE AND READ 13.75 FT^3/LB OF DRY AIR BETWEEN THE 13.5 AND 14.0 LINES
DEW POINT TEMPERATURE (DPT)	MOVE HORIZONTALLY TO THE LEFT AND READ 45° FROM THE SATURATION TEMPERATURE CURVE
ENTHALPY (H)	INTERPOLATE AND READ 25.8 Btu/LB BETWEEN THE 25 AND 26 ENTHALPY LINES WHICH RUN DIAGONALLY DOWNWARD, LEFT TO RIGHT

FIGURE 22. Psychrometric chart.

TABLE VII. Indoor pollution sources.

POLLUTANT	SOURCE	EFFECT
Asbestos	Pipe and air duct insulation	Carcinogenic
Radon	Building materials from rock and soil and uranium ore deposits under building	Carcinogenic
Vinyl chloride	Most plastics	Carcinogenic
Environmental tobacco smoke (ETS) (benzopyrene)	Smokers and ventilation systems that mix smoking area air with nonsmoking area air	Nasal and eye irration offensive orders, respiratory problems
Carbon dioxide	People	Stale air complaints
Carbon monoxide and nitrogen dioxide	Fossil-fueled heaters and engines--parking garages	Nausea, dizziness, serious health problems
Formaldehyde	Certain foam insulations paneling, plywood, and other building materials	Fatique, dizziness, general health
Ozone	Aerosols, photocopy machines, dc motors	Respiratory problems
Excess humidity	HVAC equipment, ground moisture, and building leaks	Rot, fungus, mildew, unpleasant feeling
Trichloroethylene (TCE), Trinitrofluorenone (TNF)	Copying machines, correction fluids	Offensive order, respiratory problems

b. U.S. Standards for IAQ are being established by agencies such as the National Institute of Occupational Safety and Health (NIOSH), the Occupational Safety and Health Administration (OSHA), and the Environmental Protection Agency (EPA). OSHA guidelines on maximum levels of airborne contaminants are addressed in volume XII. ASHRAE standards, while not having force of law, are generally adopted by industry. ASHRAE standards on IAQ and ventilation are currently in revision.

4.13.1.6.2 Temperature, humidity, noise, and other factors. The effects of temperature, humidity, and noise on personal comfort are subjective, varying with the individual and the season of the year. Figure 23 shows the acceptable ranges of temperature and humidity for workers engaged in administrative duties, as determined by ASHRAE. Noise, defined as unwanted sound, can cause irritation and distraction to the occupants of a room or space. The selection and positioning of power production and environmental control equipment must take into account the creation of undesirable noise. Table VIII defines noise parameters currently used in environmental control. Other factors which affect personal comfort and performance are the arrangement of furniture and equipment in a room, color schemes, and lighting levels.

4.13.1.7 Heat. Much of environmental control theory and operation involves the generation, removal, and control of heat. This section addresses basic definitions and parameters that relate to building construction and environmental control.

4.13.1.7.1 Types of heat. There are three types of heat: sensible, latent, and radiant.

a. Sensible heat is the basic, physical property of a material, caused by its molecular motion, which can be measured as temperature. As molecular activity increases, more heat is produced and a higher temperature is observed.

b. Latent heat is related to humidity or the presence of water vapor. Latent heat represents the energy required to create the water vapor.

c. Radiant heat is actually infrared radiation, and is not the result of molecular motion. Radiant heat is given off by objects which have a higher temperature than their surroundings. Dull black objects are the best emitters of radiant heat, and light-colored shiny objects are the poorest. The radiant heat received by other objects in the surroundings is converted to sensible heat in those objects, as a result of increased molecular motion.

4.13.1.7.2 Heat transfer. There are three modes of heat transfer: conduction, convection, and radiation.

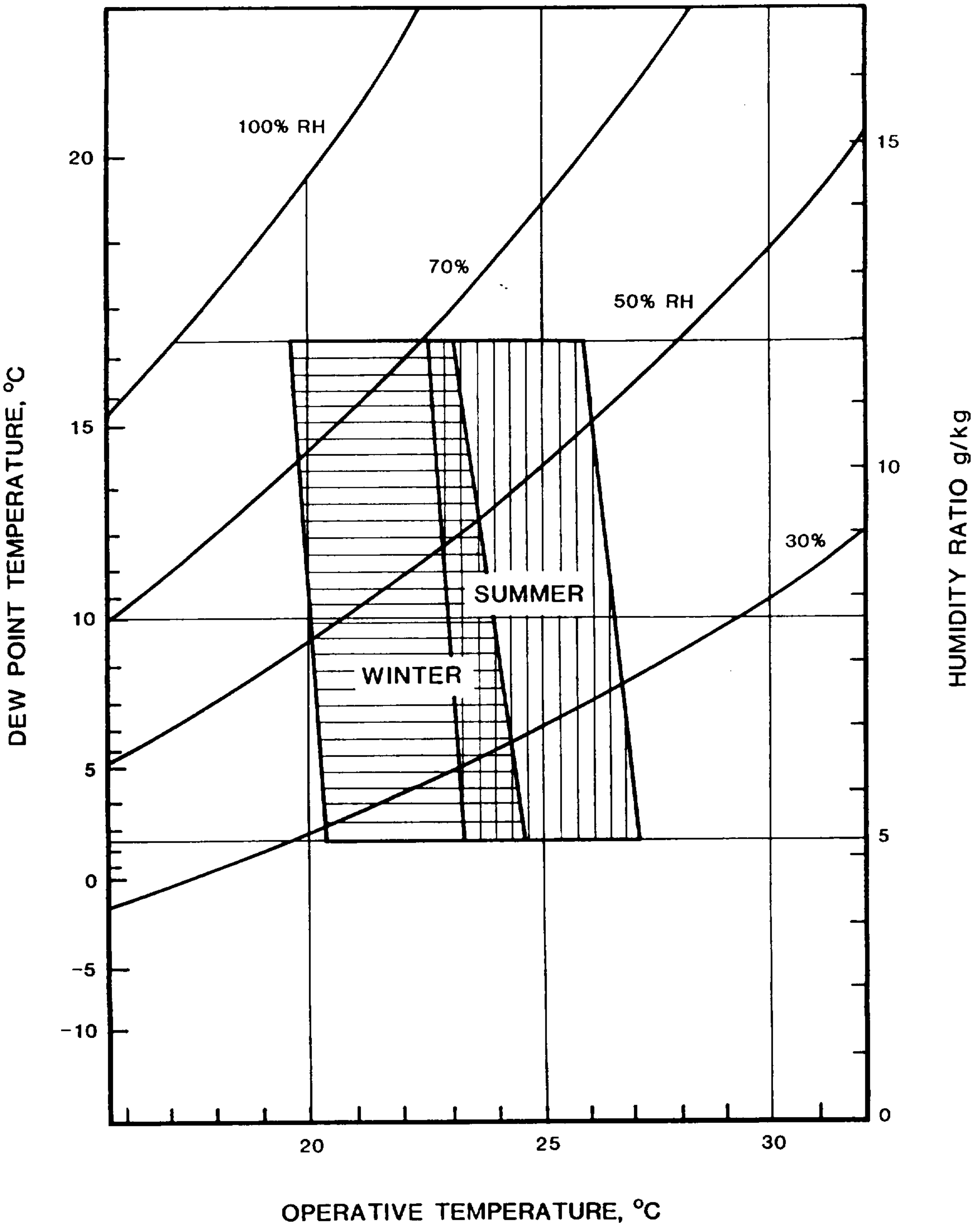


FIGURE 23. Acceptable ranges of temperature and humidity.

TABLE VIII. Noise Parameters.

Noise power	Expressed in dBa units, which are referenced to -85 dBm (3.16 picowatts)
Phon	Subjective unit of loudness. One phon is the loudness level of a 1000-hertz tone at 1 dB. Scale is nonlinear.
Sone	Subjective unit of comparative loudness. One sone is the loudness of a 1000-hertz tone at 40 dB. Scale relates to dB and is nonlinear.
Noise criteria	ASHRAE concept of noise levels for given frequencies. See volume III.
Room criteria	ASHRAE concept of noise levels for given frequencies. See volume III.

a. Conduction is the mode in which sensible heat is transferred when bodies or materials with different temperatures come in contact with one another. The higher rate of molecular activity in the warmer body transfers energy to the cooler material, resulting in increased molecular activity in the cooler material and a corresponding rise in its temperature. On a cold winter day, the indoor heat is transferred to the outdoors, through the building walls, by conduction. Similarly, a radiator heats surrounding air by conduction.

b. Convection also involves the flow of sensible heat. In the convection mode, a medium, usually a liquid such as air or water, is first heated by conduction, and then moved to another area or location of lower temperature. The heated medium transfers its energy to the area of lower temperature by conduction. The transfer of heat from the original heat source to the area of lower temperature is considered to be the convection process. An example of convection heat transfer is the functioning of a steam heating system in a building.

c. Radiation differs from conduction and convection in that it does not require the presence of an intermediate material or substance to transfer heat. In the radiation process, heat is conveyed by electromagnetic waves in the infrared spectrum (between the extremely high frequency (EHF) and visible light bands. The heat being conveyed is radiant heat, not sensible heat. Radiation heat transfer acts similarly to light transmission in that it is unaffected by gravity and moves equally well in all directions.

4.13.1.7.3 Heat measurement. The common unit of heat measurement in the U.S. HVAC industry is the British thermal unit (Btu). In metric, the calorie is used, The amount of heat required to produce a unit change in temperature of a substance is called the specific heat of that substance; Another important heat parameter is heat flow, which is measured in Btu/hour. Building heat losses and gains are important factors in HVAC planning.

a. Building heat losses fall into two general types - transmission and infiltration. A transmission loss is the transfer of sensible heat from a warmer to a colder area, such as the loss of heat through building walls and windows during winter. Infiltration losses refer to the energy required to heat cold outside air that leaks into a building through doors, windows, cracks, and other openings. The required energy includes both sensible heat and the latent heat associated with the addition or removal of humidity. Outside air brought into a structure for ventilation purposes must also be conditioned to meet design parameters.

b. Heat gains within a building occur much in the same way as do heat losses, through transmission and infiltration. Solar radiation also produces heat gains. The internal generation of heat by equipment and personnel can be significant, especially in electronic facilities. Large computers generate significant amounts of heat. While this heat must be removed, some form of energy-saving heat recovery should be considered.

c. Effective control of heat gains and losses is achieved through intelligent building planning. Local climate and geographical location should be considered in the architectural design and in the selection of construction materials and HVAC systems. Complete and accurate site survey information is essential.

4.13.2 Site survey environmental factors. Much of the data gathered during the site survey can be used in the design of buildings and the selection of HVAC equipment. These data must be accurate and complete, so that the environmental control system is capable of meeting the precise indoor conditions required by DoD electronic facilities. While meeting mission reliability and survivability criteria is the primary purpose of all supporting systems, efficient operation, energy conservation, and protection of the environment should be addressed throughout facility planning.

4.13.2.1 Climate. Essential information required on the local climate includes seasonal temperature ranges, amounts of precipitation, wind conditions, and frequency of unusual or severe weather. Basic climatic data for most locations of DoD interest are available in weather engineering documents of the military departments (TM 5-785, NAVFAC P-89, AFM 88-29). The National Weather Service and the National Climatic Data Center, agencies of the National Oceanic and Atmospheric Administration (NOAA), are other valuable government sources. ASHRAE also provides weather data for the U.S. Other potential weather data sources, especially for local details, include U.S. Air Force bases, airports, local governments, colleges, and universities.

4.13.2.2 Geographical features. Solar energy, bodies of water, vegetation, prevailing wind conditions, and terrain characteristics are local geographical features that should be identified in the site survey. Knowledge of these features can be applied when decisions concerning architectural design, building orientation, and selection of HVAC equipment are being made. Effective utilization of local geographical features can minimize energy consumption.

4.13.2.3 Site resources. All potential on-site support activities, such as communications, utilities, maintenance, transportation, supply, housing, and recreation facilities, should be identified in the site survey for possible use. The local proximity of DoD and other government activities is particularly important, especially in remote and overseas locations.

4.13.2.4 Local utilities. In most areas of the U.S. and foreign countries, local utilities can be used.Locally provided electrical power is addressed in detail in volume II. The decision to use local commercial or government-provided electrical power and the extent of backup systems will be based upon site survey data. The local availability and cost of coal, oil, and natural gas will be determining factors in the selection of heating, cooling, and power generation equipment. Natural gas is considered to be an interruptible fuel source. The local water supply must also be evaluated for quality, cost, reliability, and compliance with U.S. standards.

4.13.2.5 Local support activities. The capability of local civilian contractors, merchants, and other service providers to furnish support to a DoD facility should be evaluated by site planning personnel. Other factors to be considered in the decision process are the general geopolitical climate and economic stability of the area.

4.13.3 Building construction and design conditions. Structures provided to house fixed DoD communications and data processing facilities are designed primarily to support mission equipment. This section addresses construction parameters and design criteria for DoD electronic facilities. The basic requirements for HVAC equipment selection are established from these data.

4.13.3.1 Heat transfer properties. All walls, ceilings, roofs, and floors of a building, by virtue of their materials and construction, modulate the flow of heat through them. These heat transfer properties are very important in estimating the amount of heating and cooling capability a building needs to maintain desired indoor temperature and humidity conditions. In construction industry parlance, heat transfer characteristics are described by the terms conductivity, conductance, and resistance.

a. Conductivity indicates the amount of heat a unit section of homogeneous material will transmit under given temperature conditions.

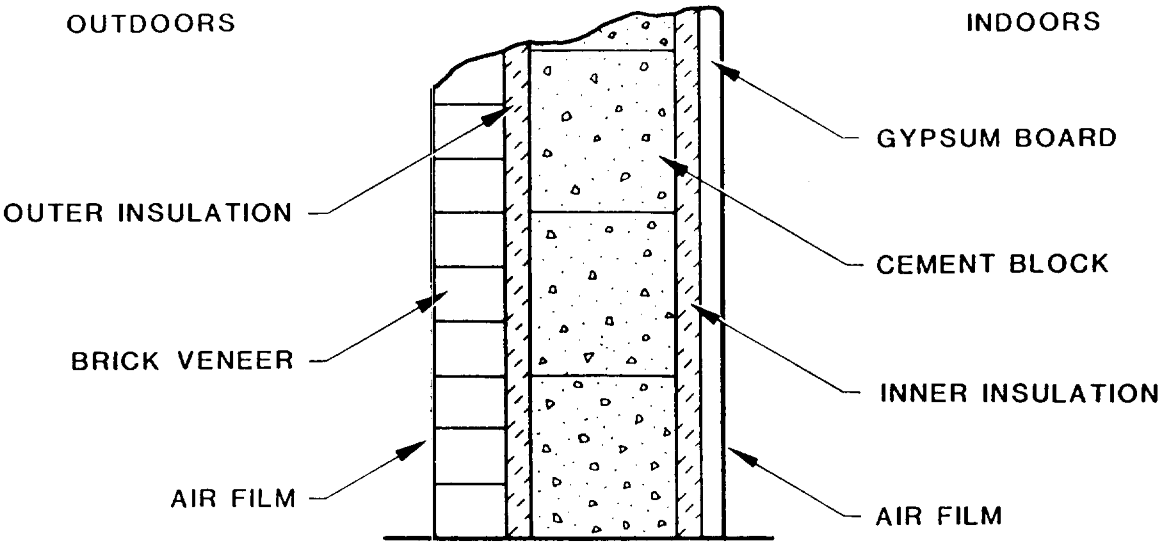
b. Conductance indicates the amount of heat a standard section of nonhomogeneous material will transmit under given temperature conditions.

c. Resistance is defined as a measure of the ability of a material or substance to impede or insulate the flow of heat and, therefore, has a reciprocal relationship with conductivity and conductance.

4.13.3.2 Practical calculations and design conditions. Building assemblies and sections are fabricated in many ways from a variety of materials. The insulating quality of these sections must be calculated from the heat transfer characteristics of the material used. Two commonly used parameters are the U-factor and the R-value. When these conditions are established, the required capabilities of HVAC equipment can be determined.

The U-factor of a building assembly is the sum of the heat transfer properties (conductivity and conductance) of its component parts, including air spaces and wind effects on exposed surfaces.

b. The R-value is the reciprocal of the U-factor, used to quantify the insulating quality of an assembly. Figure 24 shows how the insulating qualities of a typical wall are calculated. The example shown on this figure is somewhat simplified. Other factors to be considered in design efforts include moisture content of materials, vapor barriers, and especially solar effects.



COMPONENT	R
1. OUTSIDE SURFACE AIR FILM (WIND @ 15 mph)	0.17
2. BRICK (4 IN)	0.44
3. OUTER INSULATION (2 IN)	14.49
4. CONCRETE BLOCK, 3-OVAL CORE (8 IN)	1.11
5. INNER INSULATION (1 IN)	7.19
6. GYPSUM WALLBOARD (0.5 IN)	0.45
7. INSIDE SURFACE AIR FILM	0.68
	R_T = 24.53
	U_T = 0.041

IF THE BRICK VENEERED BLOCK WALL WERE 8 FT HIGH AND TWELVE FT LONG, AND THE DIFFERENCE BETWEEN THE INDOOR AND OUTDOOR TEMPERATURES WAS 22°, THE HEAT TRANSMISSION OF THE WALL WOULD BE CALCULATED AS FOLLOWS:

$$\text{BTU/HR} = \text{AREA X } U_T \text{ X TEMP. DIFFERENCE}$$
$$= (8 \text{ X } 12) \text{ X } 0.041 \text{ X } 22 = 86.59$$

FIGURE 24. Conerete block wall insulating qualities.

TABLE IX. Recommended design conditions for DoD electronic facilities.

OUTDOOR	
Winter	
Critical areas	99-percent dry-bulb and mean coincident wet-bulb temperature
Technical areas	97-percent dry-bulb and mean coincident wet-bulb temperature
Summer	
Critical areas requiring close tolerances	l-percent dry-bulb and l-percent wet-bulb temperature
Critical areas not requiring close tolerances and technical areas	2.5-percent dry-bulb and mean coincident wet-bulb temperature
INDOOR	
Computer rooms	Temperature of 72°+2°F (22°+1°C), a relative humidity of 45+5 percent, and an air filter efficiency (spot dust) of 60-65 percent. Spaces which house ancillary devices and materials, such as magnetic tape and storage disks, call for similar conditions, although tolerances may not be as critical.
Transmitter buildings	Temperature up to 90°F (32°C) (for locations with older nonsolid state equipment) Temperature should be high enough to preclude damage from moisture, even in locations of high humidity, using only ventilation, otherwise a temperature of 90°F (32°C) and relative humidity of 50±10 percent.
Electronic equipment buildings/rooms humidity	Temperature of 75°+5°F (22°+2°C), relative humidity range of 40-60 percent, and an air filter efficiency (spot dust) of 60-65 percent.
Other technical areas including power production, UPS, and battery rooms	See volume II.
Admin/personnel areas	Temperature range of 68 to 80 °F (20 to 27 °C) relative humidity range of 30 to 70 percent.

c. The heating load of a building is the amount of heat per unit time (Btu/hr) that a heating system must deliver in order to maintain indoor design conditions. Similarly, the cooling load is the heat rate that a cooling system must remove from the building.

d. Design conditions are indoor and outdoor environmental parameters used to determine HVAC equipment requirements. Outdoor conditions are selected fom weather data. Indoor conditions are established to provide a suitable environment for mission equipment and personnel. Table IX contains recommended indoor and outdoor design conditions for DoD electronic facilities. These recommended conditions are provided as guidance. Operating parameters recommended by equipment manufacturers should also be considered.

4.13.4 Environmental equipment and systems. There is no standard type of environmental control system for DoD communications and data processing facilities. The two primary considerations in designing a system are supporting mission equipment and personal comfort. HVAC equipment is selected to provide the indoor design conditions that are established for every room and space of a building. Some areas, such as computer rooms, require precise operating conditions and are often provided with dedicated environmental systems. These dedicated systems are commonly backed up by the main building systems. Personal comfort is very subjective, influenced by temperature, humidity, noise, pollution, drafts, lighting, and so forth. Most electronic equipment operates within the comfort range of personnel. Environmental control systems are categorized into two general types, central plant and unitary. Central plant refers to a centralized installation that services all or most of the rooms in a building or two or more buildings. A unitary device services one specific room or space. A window air conditioner is a unitary system. Environmental systems which combine both the heating and cooling functions are classified by the medium they use (air or water) for the convection heat transfer processes. The terms "all-air," "all-water," and “air-and-water” systems are in common usage in the HVAC industry.

4.13.4.1 Heating. There are five general categories of heating systems: forced-air, hot water, steam, radiant panel, and supplemental.

4.13.4.1.1 Forced-air systems. Forced-air systems are relatively inexpensive to install and are commonly used in DoD facilities. They have the advantage of being able to provide completely conditioned air to critical areas. Heating, cooling, humidity control, and filtration equipment is easily adapted to ductwork. Forced-air systems are also attractive candidates for energy conservation techniques, such as zoning individual rooms for different conditions and using cold outside air for supplemental cooling.

4.13.4.1.2 Hot water systems. Central plant hot water systems are commonly used in large installations, especially where area heating requirements vary. Accessory devices for the control of humidity and ventilation must be added to hot water systems. Rooms and spaces are equipped with terminal devices that are connected to hot and chilled water piping for control of heating and cooling. Hot water systems can be expensive to maintain.

4.13.4.1.3 Steam systems. Steam systems operate essentially the same as hot water systems. In large buildings, steam is favored over hot water where elevation pressure (weight) can become a problem. (See 4.13.1.4) Initial installation and maintenance costs are usually lower for steam systems.

4.13.4.1.4 Radiant panel systems. Radiant panel systems provide clean heating (and cooling). They are particularly well suited for spot heating applications, such as areas near building entrances. Panel systems are often used in hospitals and schools. Individual panel sections can be heated by forced air, hot water, or electrical resistance elements. Where humidity and ventilation control is required, separate equipment must be installed.

4.13.4.1.5 Supplemental heating systems. A practical way to reduce energy consumption is to recover and use heat that would otherwise be wasted. Potential sources of heat are power generators, large computers, refrigeration equipment, and solar radiation. Heat recovered from reasonably large and constant sources can supplement central or primary heating and hot water service systems. Either supply air or water can be heated through the action of heat exchanger, heat pumps, and heat pipes (see volume III). The use of abundant solar energy for heating has gained popularity in recent years in efforts to reduce the consumption of nonrenewable fossil fuels. Building components and even entire structures can be designed and positioned to collect and store the heat produced by solar radiation. The intermittent character of solar radiation, of course, requires that a conventional backup or secondary system be provided.

4.13.4.2 Ventilating. Ventilating is the function of removing air from or supplying air to a space by mechanical or natural means. primarily to improve indoor air quality by dilution, and is normally associated with personal comfort. Air contaminants found in DoD communications and data processing facilities are generally limited to carbon dioxide from human metabolism, dust, and other residue from paper and tape.

4.13.4.2.1 Ventilation standards. The absence of ventilation standards and reduction of ventilation rates to reduce the energy costs of conditioning raw outside air have created indoor air quality problems. Efforts are currently being made within the Government and civilian industry to develop standards which will create an effective compromise between IAQ and the efficient use of energy. For DoD facilities, the minimum amount of fresh air required (based on ASHRAE standard 62) to maintain personal health is 5 cfm for each individual. Recent studies by ASHRAE on IAQ will reportedly triple this fresh air requirement to 15 cfm. Normal ventilation rates of 10 cfm in rooms without smoking and 20 cfm in rooms with smoking are recommended for DoD facilities. All outside and recirculated air in electronic and other selected facilities should be filtered. The type of filters required will vary with location, as discussed in volume III. Air velocity and room pressurization values must also be established.

4.13.4.2.2 Natural ventilation. Natural ventilation uses the wind and thermal forces to produce the indoor/outdoor pressure differentials required for air flow. Air enters and exhausts through openings in a building, such as windows, doors, chimneys, ventilators, and other specially designed orifices. Ventilators for exhaust of contaminated air are commonly installed on building roofs to make maximum use of prevailing winds. Monitors are installed to adjust ventilation air flow for existing wind and temperature conditions. Filtration and humidity control of outside air is normally required. Natural ventilation does not provide the precision control of indoor air required in critical and technical areas, especially where computerized devices are operated.

4.13.4.2.3 Mechanical ventilation. DoD electronic areas are provided with mechanical ventilation systems “fit employ fans and precision monitoring and control devices. F\ans maintain the necessary air pressures and flow rates. Adjustments are made for existing temperature and wind conditions. Economizer cycles should be considered for spaces other than critical areas. (See volume 111) Ventilation systems should not increase the building heating and cooling loads by introducing improper amounts of raw outside air that require conditioning.

4.13.4.2.4 Fans. Fans are designed to perform in accordance with a special set of mathematical formulas called fan laws. Fans are selected to provide required air pressures within circulating ductwork. Separate fan (air handling) systems may be used to meet the requirements of different areas of a building, especially where space-use patterns and heating/cooling loads vary.

4.13.4.2.5 Distribution of ventilation and conditioned air. Ductwork moves ventilation and temperature/humidity-controlled air to conditioned rooms. Rooms with a stable requirement for air are serviced with constant volume systems. Most electronic equipment spaces fall into this category. Other rooms with varying loads may be serviced by some type of variable volume system, using energy conservation procedures.

4.13.4.3 Cooling. The requirement for cooling varies among individual DoD facilities. It can range from no cooling required for transmitters, to moderate cooling required for receivers, to a large, critically controlled, demand for computer rooms. Moderate cooling requirements can be met through regular, central, building air-conditioning systems. Computer-based facilities are generally supported by dedicated, reliable, and closely controlled HVAC equipment. A backup capability is also provided. Dedicated systems are physically located in, or in close proximity to, computer rooms. Figure 25 is one example of a dedicated, computer room environmental control system.

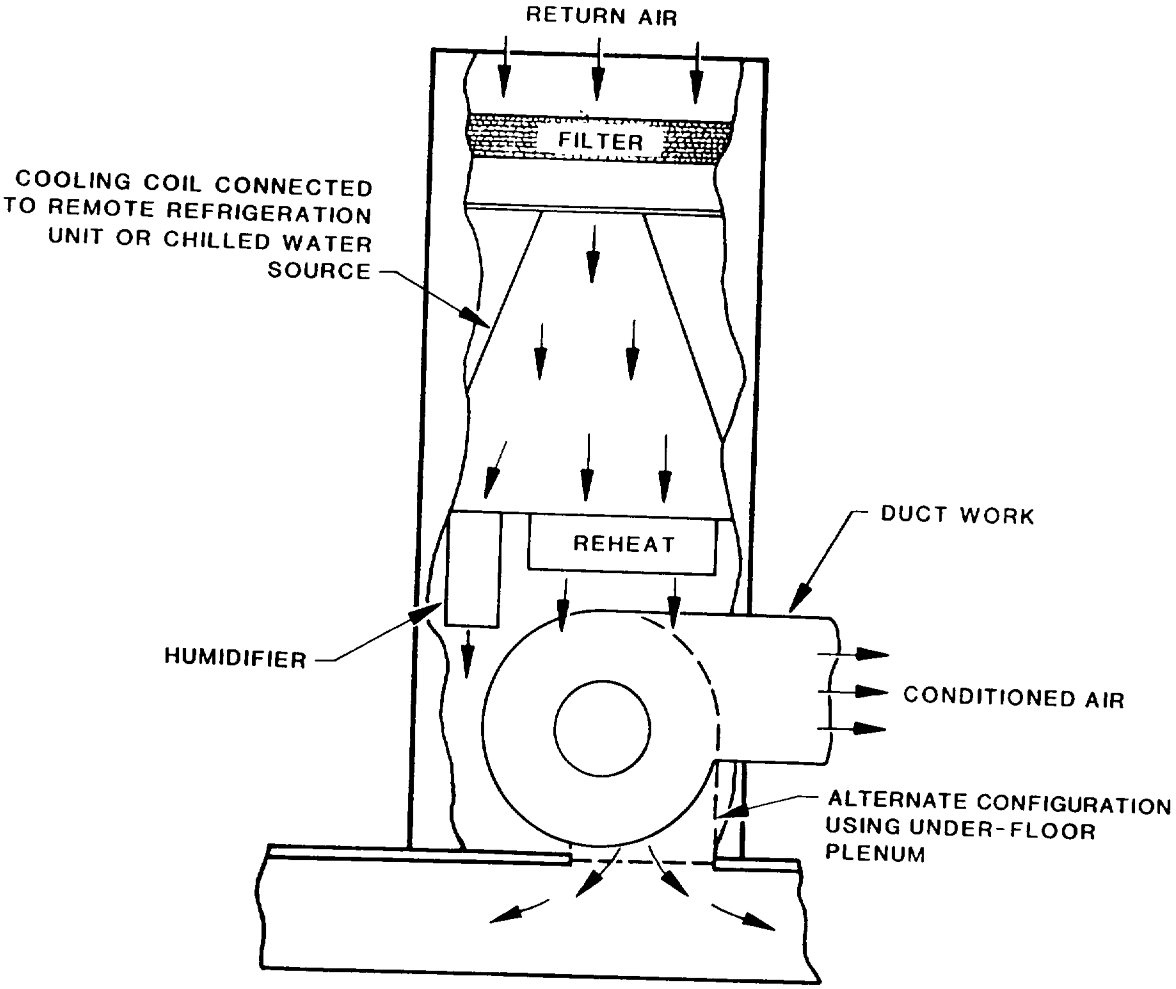


FIGURE 25. Dedicated computer room environmental control system.

4.13.4.3.1 Types of cooling equipment. The three basic types of cooling equipment are: vapor-compression refrigeration, absorption refrigeration, and evaporative cooling. The vapor compression type, used in household refrigerators, it is the most common. Heat umps operate on a reversible vapor-compression refrigeration cycle. Absorption refrigeration equipment requires the availability of large amounts of heat energy and is used mostly with chilled water systems. It has found limited application within the DoD. Evaporative type devices provide efficient, low-cost cooling in desert-like climates, where humidities are low. Evaporative coolers are sometimes used with refrigeration systems to reduce costs.

4.13.4.3.2 Special cooling equipment considerations. Large refrigeration systems use cooling towers and other types of condensers located externally to the structure being serviced. Life cycle costs for these devices can vary dramatically according to design and operational philosophy. Refrigeration cooling coils are designed to handle both sensible and latent heat and, therefore, affect humidity levels as well as temperature. Electronic devices, especially computers, generate mostly sensible heat. Normal comfort cooling loads involve considerably more latent heat. Equipment used in computer room applications should be designed for highly sensible loads. Improperly designed systems can have higher operating costs because of the need for excessive adjustments of temperature and humidity.

4.13.4.4. Humidity level control. Precise control of humidity levels in selected DoD cornmunlcatlons and data processing facilities is required to preclude damage or malfunction of sensitive mission equipment. As previously stated, the cooling load in electronic rooms is mostly sensible heat. Much of humidity control is, therefore, accomplished by the cooling equipment. For efficiency reasons, heat should be used to control humidity as much as possible. The thermostat should be the primary controller of temperature. The humidistat should be the controller for relative humidity.

4.13.4.4.1 Humidification. Methods of adding water vapor to atmospheric air vary, from simple pans containing water that evaporates naturally into passinq air, to elaborate electronically monitored and controlled devices that inject-steam into recirculating air. Humidification is sometimes accomplished during air-washing filtration processes. The preferred methods for DoD electronic facilities are steam injection and centrifugal atomizing devices. Steam systems can be closely controlled, respond quickly, and do not create excessive moisture. A clean supply of steam is necessary to preclude mineral deposits on sensitive equipment. The water supply for atomizing humidifiers should also be relatively free of harmful minerals.

4.13.4.4.2 Dehumidification. The need for dehumidification in electronic rooms is normally small. Where required, the majority of dehumidifiers remove excess moisture by either a “cooling or a sorption process. (See 4.13.1.2.) Refrigeration dehumidifiers operate under the same principles as cooling equipment. Sorption-type dehumidifiers pass the moist air over trays or other surfaces that contain special materials, called sorbents or desiccants, which adsorb water. In most devices, the collected water is removed from the sorption material by a heat-based drying and reactivation process.

4.13.4.4.3 Special humidity considerations. State-of-the-art humidity control devices, called humidistats, sense humidity variations in thin film materials that change electrical characteristics. The precision provided by these devices makes them ideal for use in DoD facilities requiring precise control of the operating environment. If the operating parameters of mission equipment permit, the relative humidity should be set at 45+5 percent, as opposed to the often-specified set point of 50+5 percent. The heat generated within a computer room is primarily sensible and the design temperature is low. The amount of air supplied in the cooling process is relatively high. Lowering the design humidity level significantly reduces the amount of air flow required and, in turn, the operating costs.

4.13.4.5 Lighting. Illumination is defined as light on a surface. There are several distinct levels of surface illumination in the DoD environment. For example, there is a level of illumination required for exterior security lighting, while interior levels are functionally related to attended or unattended equipment work areas, computer terminals, offices, etc. It is extremely important to provide adequate lighting, but illumination above the visual comfort level wastes energy and adds to the building cooling load.

> NOTE: It is important to realize that the reduced power consumption of modern computer-based electronics may result in the facility lighting load exceeding that of operational equipment. This emphasizes the need for an efficient, controlled lighting system at DoD facilities.

Unfortunately, visual comfort is subjective, and if three people enter an equipment room, one might look for the switch to provide additional light, the second might try to dim what is already on, and the third might think the illumination level is just right. As a result of these differences in perception, statistics are used to determine optimum illumination for a particular functional area. These statistics predict the percentage of personnel that are comfortable when exposed to the worst glare in a facility. This design process, called visual comfort probability (VCP), takes into account overall brightness, lighting fixture characteristics, and position. It is understandable that the determination of VCP is laborious, but computer programs are available to assist the architect or engineer.

4.13.4.5.1 Lighting terms, symbols, and units. This section introduces the major lighting terms, their units of measure, and how they are interrelated. In volume 111, basic calculations using these terms are introduced. Illumination quantities with their symbols and units are listed in table X. The basic unit, stemming from the introduction of candles around 400 A.D., is the candela (cd). All other units are derived from the candela which is the unit of luminous intensity (I) of a source of light in a specified direction. Because the candle was the first standard unit of luminous intensity, intensity levels of later developments, such as gas flames and incandescent lamps, are expressed in candelas.

TABLE X. Lighting symbols and terms.

Symbol	Concept	Metric unit	English unit
I	Luminous intensity or candlepower	Candela (cd)	Candela (cd)
Φ	Luminous flux *	Lumen (lm)	Lumen (lm)
E	Illuminance	Lumen per square meter ($1m/m^2$) (lux (lx))	Lumen per square foot ($1m/ft^2$) (footcandle (fc))
M	Luminous exitance	Lumen per square meter (lm/m^2)	Lumen per square foot (lm/ft^2)
L	Luminance **	Candela per square meter (cd/m^2)	Candela per square foot (cd/ft^2)
Q	Quantity of light	Lumen-second (lm-s)	Lumen-second (lm-s)

* Luminous flux corresponds to power in the radiation system and quantity of light corresponds to energy. Thus the lumen and the watt are the same dimensionally as are the lumen-second and the joule (watt-second).

** Luminance is also often expressed in candelas per square inch and candelas per square centimeter

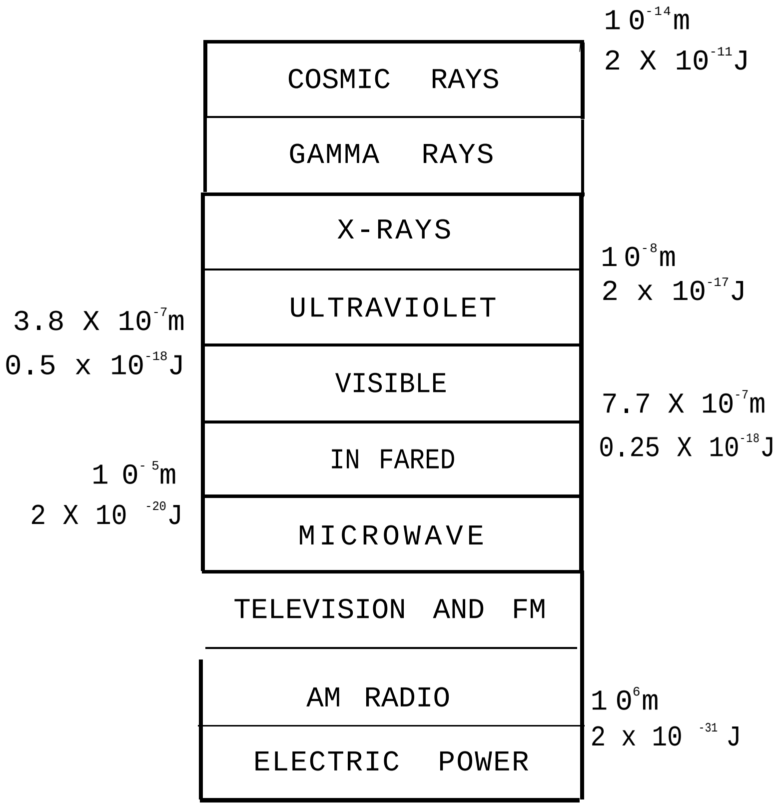
NOTE : The footlambert is a unit of luminance equal to $1/\pi$ candelas per square foot. Its use is declining, but it still appears in some literature.

4.13.4.5.2 Luminous flux. Luminous flux is the time rate of flow of luminous energy from a source. As it travels outward, it eventually strikes objects where it is reflected, transmitted, and absorbed. The unit of illuminance is footcandle (fc) in the English system and the lux (lx) in the SI system.

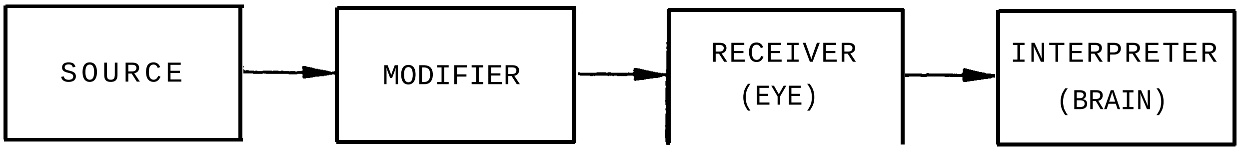
4.13.4.5.3 Coefficient of utilization. Early methods used to calculate interior lighting levels dealt only with direct illumination and ignored complex reflections from surrounding surfaces. In the 1920 period, a standard procedure was developed that included both direct and reflected lumens. This procedure was replaced in the mid-fifties by the Illuminating Engineering Society (IES) of North America standard that evolved into the present zonal cavity method which determines average illuminance. To calculate this average, it is necessary to determine the total luminous flux reaching the work plane which is composed of two components, flux directly from luminaires and indirect flux reflected from room surfaces. In the zonal cavity method, the fraction of the initial lamp lumens, which ultimately reaches the work surface (both direct and reflected), is called the coefficient of utilization (CU). CU is defined as the ratio of useful light on the lighted surface to the total emitted by the lamp in the luminaire. CU is made up of several factors such as room size, shape reflectances, and luminaire (fixture) distribution. CU tables and instructions for use are published by lighting manufacturers. (See IES Lighting Ready Reference RR-85.)

4.13.4.5.4 Human vision and brightness considerations. Luminance is often confused with the popular term “brightness,” but luminance is the visual excitation where brightness is the visual response. Brightness is a qualitative and subjective tern which refers to how a surface appears to an observer. For unexplained reasons, natural light is acceptable at brightness levels that would be classed as glaring under artificial light. Brightness is not a fixed property, but varies with the eye’s adaption to simultaneous and sequential contrast, as well as the entire field pattern of brightness. An absolute brightness scale does exist as a mental phenomenon, but it is vague and indefinite. The eye, however, is very precise in estimating the relative brightness of two adjacent lights of the same quality. Uniform brightness is monotonous; therefore, backgrounds should have sufficient brightness and interesting contrasts. Preferred lighting installations use a combination of diffuse and directional illumination. A balanced brightness design requires engineering experience and skill.

4.13.4.5.5 Physical factors of seeing. The purpose of lighting in a DoD facility is to see a visual task and accomplish visual work. There are five major factors involved in the seeing process, namely object size, contrast, length of time the object is viewed, luminance, and color. The optimization of the first four factors of seeing creates the potential for excellence in visual performance, but does not guarantee it due to fatigue, training, and other physical factors. The fifth factor, color, affects perception of objects and the spaces they occupy. Figure 26a illustrates how small a portion of the electromagnetic frequency spectrum is occupied by visible light. This portion is called the visible spectrum. The visible spectrum means that any energy produced in this narrow band will produce the sensation of vision when it stimulates a normal human eye. Figure 26b depicts the seeing process. The first requirement is a source of visible radiant energy--the sun, or one of many electrical or flame sources. The next requirement is some kind of a light modifier--a natural or manufactured object that reflects or transmits light to the eye. Objects in this category are called modifiers because in most instances they will alter the spectral character of radiation from the source. The third element in seeing is the eye, which serves as a light receiver and a processor before sending messages to the brain. The brain receives signals from the optic nerve, decodes them and provides the viewer with perception and understanding of the object. Voluwe III will discuss how these factors are related and how to select illuminance categories for optimal visual performance.



A. THE ELECTROMAGNETIC SPECTRUM: WAVELENGTHS IN METERS (m) AND PHOTON ENERGIES IN JOULES (J)



B. PHYSICAL FACTORS OF SEEING

FIGURE 26. The electromagnetic spectrum and physical factors of seeing.

4.13.4.5.6 Lighting controls. Effective lighting control is crucial to energy efficient building design because the lighting load may exceed that of installed electronic equipment. Additionally, the effect of lighting load on HVAC design cannot be over emphasized. The various methods used to control lighting fall into two general categories. In the first category, the light is either on or off. In the second, in addition to on and off, the amount of energy consumed and the illumination level can be varied somewhere in between the on and off state. This section discusses some of the methods used to accomplish luminaire switching and level control.

a. Snap switches. In certain applications, such as warehouses, circuit breakers are used to turn off the entire lighting load. However, from the energy standpoint, this method is inefficient, especially during cleaning and maintenance operations when less luminaires are required. Some states have adopted energy codes that require at least one switch per lighting circuit. In those states, the use of circuit breakers for lighting control is illegal. Wall-mounted, snap switches are still the least expensive lighting control method and can be quite effective when three-way and four-way types are used to effect control from different locations.
the simplicity of zonal and level control using wall switches to control 20 luminaires, each with four lamps, connected to a 277-volt ac source. In addition to the individual room control, the lighting in room 100 has two levels with each switch operating one-half of the lamps in each luminaire. The main disadvantage of snap switches is that if long runs are required to the luminaire being controlled, voltage drop can be appreciable.

b. Time switches. The use of snap switches puts the responsibility for energy conservation on the individual. Since this is not always a reliable method, time switches can be used. With a time switch, the person entering the room turns on the lights, but does not turn them off when departing. Time switches with intervals from zero to a few minutes or zero to several hours are available at reasonable cost. Application of these units should be considered in such places as storage areas and bathrooms.

c. Photocells and time clocks. The controls previously discussed require human action to initiate a change. On the other hand, time clocks and photocells do not, and they are ideal for use in controlling outdoor light systems. These systems are typically more expensive to install, but convenience and long-term energy savings soon offset this disadvantage. Photocells also play an important role in dynamically controlling interior illumination levels in buildings where "daylighting" is used to conserve energy. A description of how daylighting can afford significant energy savings is provided later in this handbook.

d. Motion-detector switching. As previously mentioned, reliance on humans to turn lights off is questionable. In some cases, motion detectors (ultrasonic detectors) used for security systems also provide lighting system control interfaces. Motion detectors can also be used inside structures to turn on lights when an intruder (or worker) enters an area. When motion is no longer detected, an interval timer turns off the lights. This method of light control tends to be expensive, but is a logical choice of a motion detection-based security system is in place, and is integrated with a low-voltage system as described in the following paragraph.

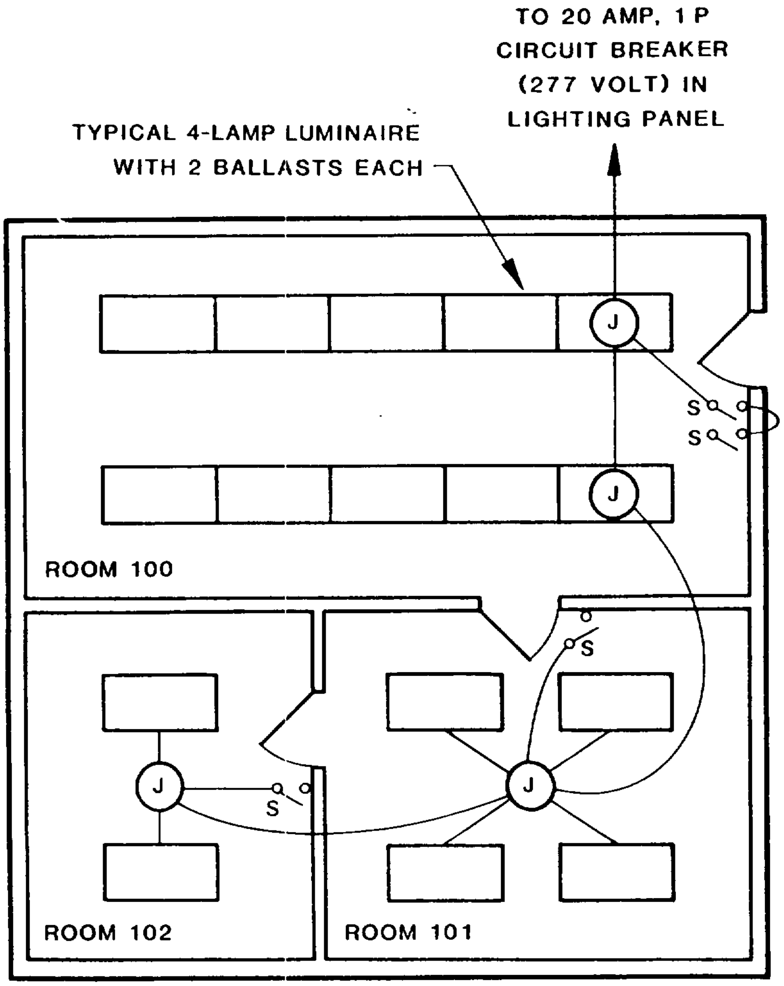


FIGURE 27. Use of wall switches for zonal and level lighting control.

e. Low-voltage switching. The control of lighting using low-voltage switching is not new, but has recently gained wider acceptance. Low-voltage switching provides the capability to control loads from a distance, control several different loads from one location, or control one load from several locations. For example, if all lights are centrally switched off in an office complex at closing time, then a local low-voltage control can be used to turn on area lights for the overtime worker. A low-voltage (usually 24 volts or less) system offers greater electrical safety, and lower costs, due to the use of smaller gage wires which are normally installed without conduit. Flexibility is improved because several luminaires can be controlled from a single relay. With the increasing use of computers to control building environment, the use of low-voltage lighting control becomes even more attractive.

f. Dimmers. Dimmers are the most popular method of illumination level control and are available for incandescent, fluorescent, and high-intensity discharge (HID) luminaires. Early incandescent dimmers were usually resistive in nature and succeeded in reducing the level of illumination, but used the same power through heat dissipation in their resistance element. Recent applications of the thyristor in solid-state dimmer circuits have resulted in energy savings when luminaires are operated at reduced power. Figure 28 shows how the switching action of a solid-state dimmer results in reduced power consumption. This type of dimmer, though energy efficient, creates rf noise that may not be acceptable in the DoD environment unless newly designed dimmers with special filters are used.

g. Daylighting. Daylighting, or the deliberate use of solar radiation as a source of heat and light in building design, is discussed in several parts of this handbook. This section concentrates on the visible light portion of solar radiation. Only 50 to 60 percent of the radiant energy reaching the outer limits of the earths atmosphere actually reaches the earth's surface. Losses in radiant energy are due to scattering, reflection and absorption in the atmosphere. The earth’s rotation around its polar axis causes daily changes, and rotation around the sun causes seasonal changes in the amount of radiant energy received. Figure 29 illustrates the concept of seasonal changes in amount of solar radiation received on the surface of the earth. Daylight entering a space must be analyzed in terms of quantity and quality. Altough daylight may be sufficient in quantity to reduce or turn off artificial lighting, poor quality daylight may result in discomfort and a reduction in human performance. Daylighting in the conventional sense may not be appropriate in most DoD facilities due to the increased vulnerability caused by the fenestration (windows) required. A design concept for smaller facilities utilizing solar radiation for heating, cooling, and lighting while maintaining building security is presented in appendix E of this handbook.

4.13.4.5.7 Lighting innovations. Modern lighting equipment and controls cost more to install, but lower total cost results when both operating and initial costs are considered. Recent light source developments have concentrated on the high intensity discharge (HID) types. Even though HID technology has brought about significant reductions in specialized lighting costs, fluorescent lamps are presently the most efficient for general lighting of building interiors. Application of solid-state circuitry to the

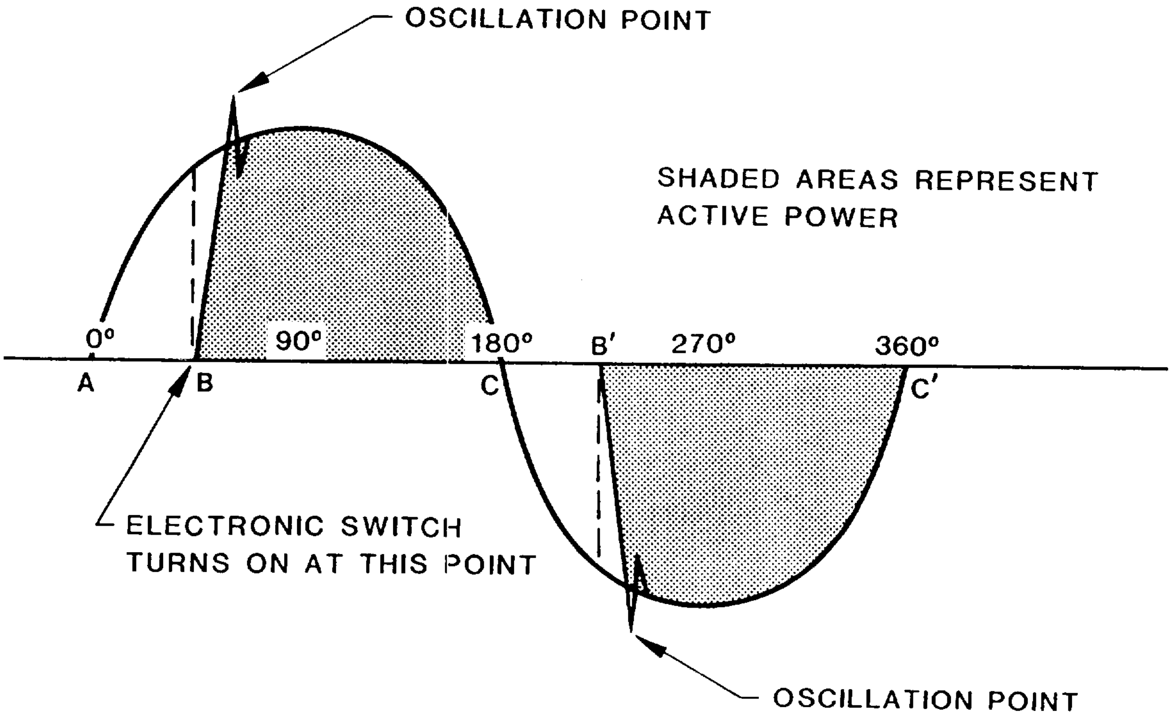


FIGURE 28. Power consumption using solid- state dimmer.

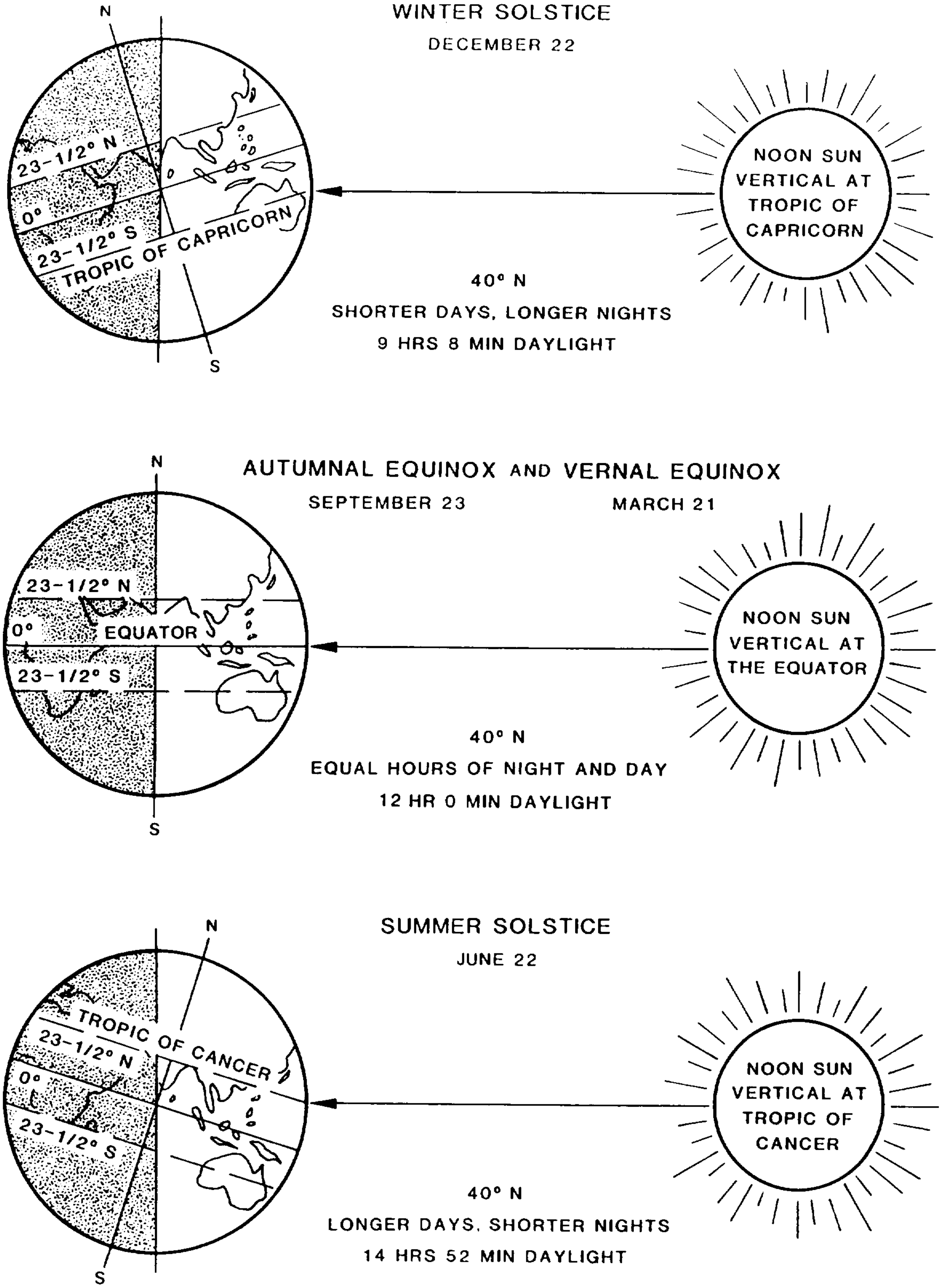


FIGURE 29. Seasonal changes in solar radiation.

fluorescent ballast and lamp are expected to enable this source to keep pace with future HID developements. Incandescent lamps are also undergoing significant energy saving changes through the introduction of halogen technology. Newly developed high pressure sodium and metal halide lamps have also resulted in increased lumens per watt (efficacy improvement). Information to aid in selection of lighting fixtures for DoD application is included in volume III.

4.13.4.6 Electrostatic discharge (ESD) control. With the ever increasing sensitivity of electronic equi ment, the damage that can result from electrostatic discharge (ESD) has become a major concern to manufacturers and users alike. This threat results when people or objects accumulate a static charge of up to 15 kV and then come in contact with a sensitive part to discharge through a grounded or ground-coupled point. Several existing industry standards, using simple resistance-capacitance networks, attempt to simulate the human ESD model. These simulated network values for the human body range from capacitances from 100- to several-hundred pf and resistances from 150 to 1500 ohms. Discharges from humans through a metal object can result in a spike characterized by a 10- to 30-A current with rise times of less than one nanosecond. Methods to limit damage or upset to electronic equipment by ESD are discussed in other volumes of this handbook, but table XI illustrates the effect that relative humidity level has on some ESD-generating mechanisms.

4.13.4.7 Water supply and waste treatment. This section identifies the primary items that are considered in designing the water supply and waste treatment system for a DoD installation.

4.13.4.7.1 Water usage and sources. The three classifications of water usage are: domestic, industrialnd fire protection. Table XII shows estimated domestic and industrial water requirements. Fire protection information is contained in appendix B. All demands for water should be met through use of potable water, if possible. When potable water supplies are linited or costly, nonpotable water may be used for industrial and fire protection uses. Site water will be supplied from either a local public system or from site resources, such as ground water (wells), surface water (rivers, streams, and ponds), or storage (tanks). The most desirable source is from a local public system, assuming that U.S. quality standards are met and that current and anticipated future demands can be satisfied.

4.13.4.7.2 Water quality standards and treatment. Most public water supplies in the United States provide an acceptable product. The quality of water supplies in foreign countries varies and should be either verified by a recognized U.S. authority or thctroughly tested before a decision is made to use them. In the U.S., basic standards for domestic water quality are established by the Environmental Protection Agency (EPA), with modification by state agencies. The harmful effects of contaminants are negated by the application of chemicals, filtration and screening, aeration, and settling. Special treatments for the control of corrosion and scale buildup in both heating and cooling equipment may be required. See volume III of this handbook.

TABLE XI. Electrostatic voltage generated at varying humidities.

Static Generation Means	Electrostatic Voltages	
	10% RH	40% RH
Removal of plastic wrap from circuit board	26 kV	11 kV
Person crossing vinyl-covered floor	12 kV	5 kV
Person crossing carpet-covered floor	35 kV	15 kV
Maintenance worker at bench	6 kV	1 kV

RH = Relative Humidity

TABLE XII. Estimated domestic and industrial water requirements for permanent installations; daily gallons per capita.

DOMESTIC	
USE	REQUIREMENT
Dormitories	170
Family housing	150
Workers (per shift)	50
Hospitals (per bed)	200

INDUSTRIAL				
Use	Unit	Requirements		
		min.	avg.	max.
Air conditioning:*				
with conservation	gpm/ton		0.05	0.10
without conservation	gpm/ton		2.50	4.00
Cooling-diesel engines:**				
with conservation	gpm/bhp		0.01	0.02
without conservation	gpm/bhp	0.25	0.33	0.40
Cooling-steam power plants:				
with conservation	gal/kWh	0.80	1.30	1.70
Motor vehicles	gpd/car	30		50
Restaurants	gal/meal	0.5		4.0

* Once-through systems which pass potable water through cooling coils and then to drains are wasteful hnd are not recommended.

** Lowering cooling water operating temperatures through use of remoted radiators can reduce the amount of makeup water required to overcome evaporation and treatment losses. If well water is used, it can be recycled after treatment.

4.13.4.7.3 Water distribution and storage. Water distribution systems on DoD installations are installed in accordance with the appropriate military department civil engineering standards. Distribution systems are made up of arterial mains and distributors. All major water users are connected to two individual mains. Pumps and gravity provide the line pressures necessary to meet user requirements. Ground level, underground, and elevated tanks are used for water storage. Hydropneumatic tanks are a special type of container for small storage requirements, which are pressurized with compressed air to facilitate water distribution.

4.13.4.7.4 Waste water treatment. Waste water is generally collected and transported to a centralized treatment plant in a sewer system. The treatment plant may be operated by the DoD or by a local civilian authority. Sanitary systems handle drainage from kitchen sinks, toilets, laundries, etc., while storm systems handle rain water from roofs, areaways, and other areas exposed to weather. Devices called interceptors are installed in drainage systems to isolate potentially dangerous or disruptive substances for separation.

4.13.4.7.5 Domestic hot water service. Hot water is provided from storage or instantaneous devices. Water is heated by the burning of fuels, electricity, solar collection, or energy recovery. Large central heating plant boilers are commonly equipped with coils for hot water service. Solar water heaters are being used increasingly with conventional systems to reduce costs. Waste heat, such as that produced by power generators, can be used to produce hot water through heat exchanger action. See 5.8.2 concerning cogeneration.

4.13.5 Special considerations for communications and computer-based euipment. See MIL-STD-1472/l.) This section summarizes the special aspects of environmental control that apply to DoD electronic activities. Refer to table IX for indoor and outdoor design conditions for conmnications and data processing facilities. Environmental control systems that support critical areas and selected technical areas should be treated as critical systems. Accordingly, they should be redundant and connected to backup power systems. Mainframe computer rooms are usually provided with dedicated systems that control heating, cooling, air quality, humidification, and dehumidification. A dedicated system should be designed to accommodate anticipated changes and upgrades of mission equipment without serious degradation of performance.

a. In some locations, mission equipment will generate enough heat to preclude the installation of a central heating system. A temporary heating source should be available to maintain a temperature of 68°F (18.3 °C) when mission equipment is not operating. Heat recovery applications should be considered for installations with mission equipment that generates large and stable amounts of heat.

b. Air filtration and ventilation rates for computer rooms and other carefully conditioned electronic spaces should be based upon the anticipated quality of outside makeup air. In locations of high pollution, such as large urban or industrial areas, special high-efficiency filters and even air quality treatment may be necessary. Air filtration systems should be equipped with monitoring devices which verify operation and warn of filter saturation.

c. Cooling is the most important element of environmental control in many electronic installations. Cooling can be by air or water. High heat-producing electronic equipment, cooled by air, commonly includes ducts and fans to facilitate the effective distribution of cooling air within the cabinetry. Computer rooms and other critical areas should be supplied with conditioned air through a single-duct, constant volume, low velocity system. Technical and other areas can receive conditioned air through a variable air volume system. In common practice, conditioned air from the under-floor plenum is passed into the room through registers located in the raised floor or directly into equipment cabinets. Water-cooled computers usually include the necessary internal, coolant-distribution network which is connected to an external, chilled-water source. Redundant refrigeration systems are sometimes provided for reliability reasons.

d. High humidity can cause improper feeding of cards and paper, and, in extreme circumstances, the formation of damaging condensation on sensitive equipment. Low levels of humidity can promote the formation of dust and increase the potential for electrostatic discharge. The relative humidity should be maintained at 45+5 percent, unless high levels are required for mission equipment. Lower humidity levels require smaller air flow rates and reduce operating costs. To minimize humidity losses through transmission to adjacent spaces, vapor retarders should be installed in the perimeter walls of a computer room. Openings in the room envelope for ducts and pipes should be properly sealed. Keeping the room “tight” also helps maintain positive pressure. Steam humidifiers are generally preferred for sensitive electronic areas because of their clean operation and ease of control.

e. The level of illumination in a computer area is particularly important because too high a level not only increases the room-cooling load but can cause annoying reflections on display tubes. The zonal cavity method is preferred by the Illuminating Engineering Society (IES) to determine average horizontal illumination. To obtain this average illuminance, it is necessary to determine the total luminous flux reaching the work plane. This flux is composed of two components - flux which comes directly from luminaires to the work plane and flux from multiple reflections off room surfaces which also arrive at the work place. In the zonal cavity method, the fraction of initial lamp lumens (both direct and reflected) that reaches the work plane is called the coefficient of utilization (CU). This number is published in luminaire tables for various room dimensions and surface reflections. with light loss factor (LLF), these numbers are used in a formula to obtain an expression for the average work-plane illuminance. The aging of lamps and the normal dulling of lamp, work, and room surfaces provide the data required for the LLF (maintenance factor). Discomfort glare for computer operators is caused by luminaires that are too bright, are inadequately shielded, or cover too greatan area. It is also caused by reflections from mirror-like surfaces lighted by sources having concentrated beams such as computer screens. Placement of computer monitor screens should receive careful consideration in the facility design to reduce glare to a minimum. example, it has been found that the worst viewing condition is typically near the center of a wall with the viewer looking horizontally across the room.

Wherever possible, the final angle of console placement in a new facility should be determined when all lighting sources are in place and at normal brillance. Illumination levels finally selected by the designer will consider the age of worker, the speed of accuracy required by the worker, the inherent difficulty in viewing the work object, and the task to be performed. The illuminance (footcandles on task) for most DoD computer areas will be in the 50- to 200-footcandle range. IES publications, such as the Lighting Ready Reference Handbook or appropriate service document, should be reviewed by the facility planner to determine the illumination levels recommended for the various mission functions.

f. Noise levels should be maintained below 60 dBA in DoD information systems operating areas. Power and HVAC equipment that generate high levels of noise and vibration should be carefully positioned with respect to the mission operating area. Equipment which must be located in or near operating areas should be selected for low noise and vibration qualities. Construction materials with good acoustical properties are available. For example, forced-air ductwork can be designed and fabricated to reduce noise from fans and air flow. Similarly, floors and walls can be constructed with layers of air or special materials that absorb sound, and vibration problems can be reduced by mounting equipment with isolation devices.

g. Computer rooms and other selected electronic activities require precise monitoring and control to maintain design conditions. Recording the performance of HVAC equipment is highly recommended, so that mission equipment malfunctions and failures can be correlated with environmental systems. Complete automation of sensitive electronic equipment areas, using direct digital control (DDC) devices, is a controversial subject at this time. The availability of quality maintenance support for highly sophisticated and technical systems appears to be the main contention. their reliability is fully established, DDC and other cost-effective systems will be standard in DoD installations.

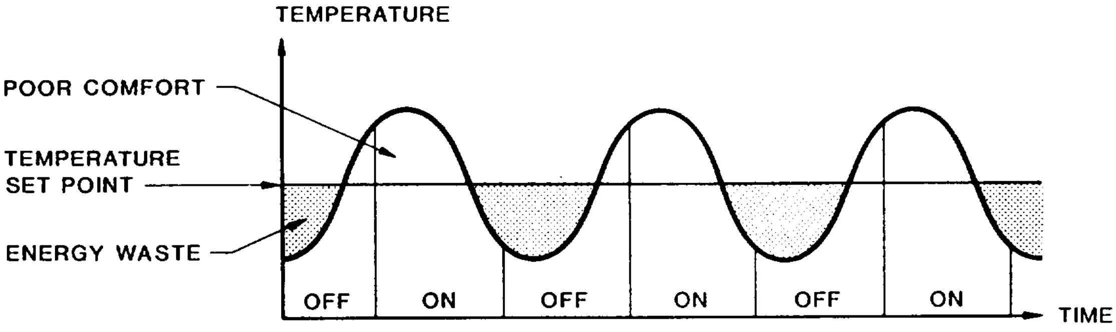
h. The use of multiple outlet surge protectors at the end of extension cords for small computers and business equipment is discouraged. These cords present a safety hazard both from tripping and from liquid being spilled in the outlet box. There are several wall-outlet surge protectors available that replace the standard wall outlet without changing the wall box. These outlets are produced by major manufacturers of electrical distribution equipment and meet UL and IEEE standards for surge protection. They are also available with locking-type plugs to reduce the chance of accidental power disconnection.

4.13.6 Environmental systems monitoring and control. A control system has two basic elements. One is a “controller” that senses a control status change, determines if the change requires corrective action and, if so, sends a corrective signal. The second element is a “controlled device,” or module, that receives the signal from the controller and takes the required action. An on/off wall thermostat is an example of a controller, as it senses a change in room temperature and sends a signal to a furnace gas valve to open. The furnace gas valve is the controlled device. When the thermostat (controller) is satisfied, a signal is sent to shut off the furnace. This system, where the controller senses the result of its actions, is referred to as a "closed loop" control system. An "open loop" control system is one that does not have feedback or the controller does not sense the reaction to its signals. An example is an outdoor thermostat that senses a drop in temperature and sends a signal to a boiler to start heating water for building heating. In this case, the controller senses changes in the outdoor temperature, but does not get feedback on the result of sending a signal to the boiler.

4.13.6.1. HVAC control. The energy crisis of the early 70's completely revolutionized HVAC control and monitoring theory. One of the most popular energy saving changes in HVAC control is known as variable air volume (VAV). This system carefully controls personal comfort and equipment parameters without heating or cooling excessive amounts of outside air. Unfortunately, without sophisticated control techniques, VAV contributes to the poor indoor air quality (IAQ) brought about by tight building design. This degradation occurs because the tight building leaks very little air which reduces the amount of outside air that can infiltrate and permits toxic fumes to accumulate. In the past, multiple zoning has been used to heat certain portions of a building while cooling others. The use of highly sopisticated HVAC systems in certain DoD electronic facilities may be inappropriate. The availability of maintenance support should be thoroughly evaluated. More information on VAV is contained in volume III of this handbook.

4.13.6.2 Microprocessor control of HVAC systems. Another major improvement in energy saving control of HVAC systems was made possible by the advent of the personal computer (PC) or microprocessor. Prior to the advent of the PC, the cost of a typical HVAC system was almost equally divided between ductwork, hardware, and labor. Now, computer-controlled energy management systems (EMS) may represent 20 percent of the total HVAC system cost.

4.13.6.3 Direct digital control. Direct digital control (DDC) is rapidly repacing pneumatic (air) control of HVAC systems in industry, but older pneumatic controls can be coupled to microprocessors through transducers. The basic building block of a CIDC system is the control or dedicated module (DM). DM set points (such as temperature, flow rates, start/stop times) can either be set manually using a screwdriver and gauge or by remote control from a central computer. Pneumatic control systems evolved from simple components performing simple functions. Pneumatic control of HVAC systems consists almost entirely of proportional movement of a damper or valve in relation to a set point and rocm temperature. Proportional systems offer some comfort and energy consumption advantages over the on/off thermostat type of operation. Figure 30 illustrates the problems with on/off control systems. "Pneumatic controls will continue to be used on smaller environmental control systems as they offer the advantage of low initial cost and ease of adjustment. The application of DDC in DoD installations will increase, but reliability and the availability of maintenance support should be the determining factors for its use. At this time, there are prohibitions against the use of DDC within some military departments.



IN THE COOLING MODE, PORTIONS OF THE CURVE ABOVE THE SET POINT REPRESENT POOR COMFORT AND PORTIONS BELOW THE SET POINT REPRESENT ENERGY WASTE. THE REVERSE IS TRUE DURING HEATING MODE.

FIGURE 30. Effects of poor temperature regulation on energy consumption and comfort.

4.13.6.4 Control systems configuration. Figure 31a shows representative connections for a heat pump without a dedicated module (DM). The DM connection, shown in figure 31b., results in a substantial reduction of interconnect wiring. The DM can sense either a space or return-air temperature and use it to control the zone temperature. By comparing the set point with the zone temperature, the DM will position the valve in the heat pump, as required, for either heating or cooling. The DM also starts the compressor and shuts it off once the required temperature is reached. Temperature setbacks for unoccupied times and alarms, based on reduced airflow (dirty filter or iced up coil), are regular features incorporated in DM design.

4.13.6.5 Effects of duct design on control systems. The recent introduction of glass fiber ducts and coiled-steel duct "1" sections has cut HVAC installation costs or permitted larger ducts for the same price. The larger ducts make low pressure (1 inch or less) systems possible with a large savings in energy costs. Low pressure systems tend to be easier to control, modify, and balance when compared to high pressure ones. Most discussions on HVAC central control concentrate on the use of ducts and dampers for air distribution; however, hydronic systems, through the use of valves, are just as easily controlled. Current National Fire Protection Association (NFPA) standards permit the use of internal sprinkler systems for hydronic heating and cooling. This option not only reduces plumbing costs, but ensures integrity of the sprinkler system. Refer to figure 35.

4.13.6.6 Integrated building automation systems. Fully integrated building automation systems offer the potential for significant reductions in energy costs through:

a. Turning lighting and HVAC systems on and off to meet the building’s occupancy schedule.

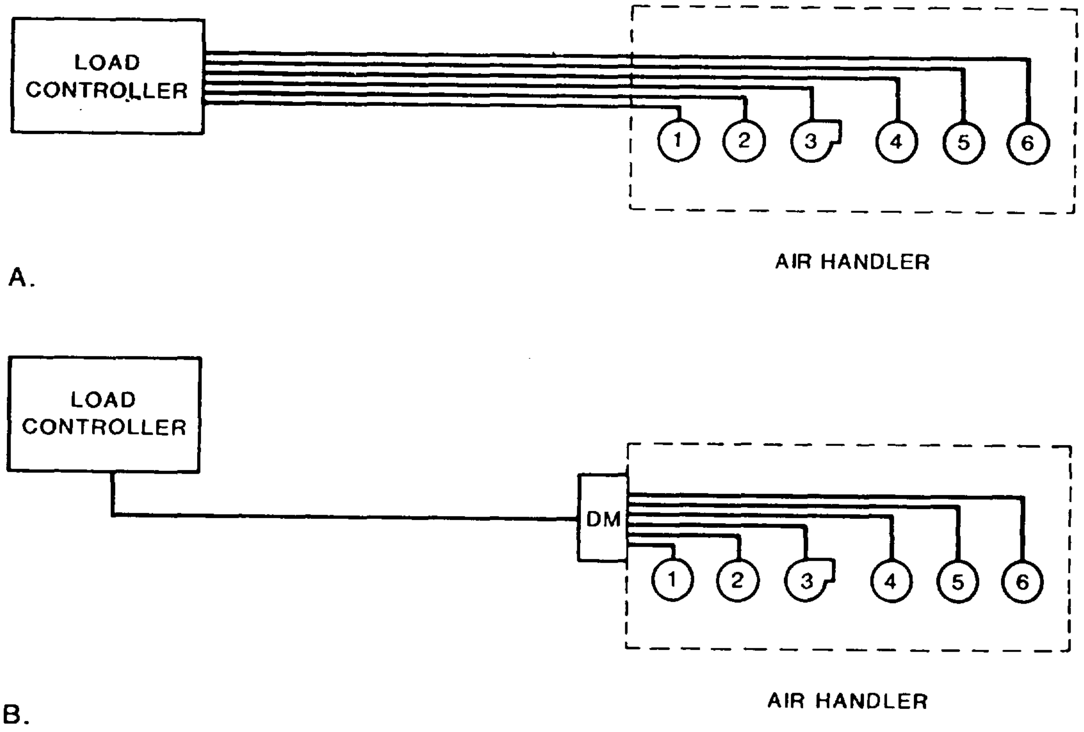
b. Reducing peak power demand.

c. Opening and closing outdoor air dampers to meet occupancy schedules.

d. Optimizing “economizer” cycles and utilizing “free cooling” when outside temperatures permit.

e. Integration with other systems such as building access and fire control.

4.13.7 Energy conservation. Methods to conserve energy should be incorporated in the design of DoD facilities as long as mission reliability is not jeopardized. The cost of energy can be a major part of life cycle costs of communications and ADP. Energy conservation should be an integral part of all planning and design effort, using data collected during site survey activities and experience factors. Energy conservation methods and techniques include energy management programs, cogeneration, energy efficient construction, and efficient HVAC equipment operation.



1. ZONE TEMPERATURE
2. 4-WAY VALVE
3. FAN START/STOP
4. COMPRESSOR START/STOP
5. AIR VELOCITY
6. SUPPLY AIR TEMPERATURE

FIGURE 31. Interconnection reductions by using dedicated module(DM).

4.13.7.1 Energy management program. DoD facilities that consume significant amounts of energy should have a full-time energy management program. The energy program manager should participate in facility planning. Recommended program activities are as follows:

a. A public relations plan to educate personnel on the goals and objectives of the program.

b. Monitor and analyze energy consumption and HVAC equipment performance.

c. Conduct energy audits.

d. Prepare reports for management.

Volume III of this handbook provides detailed information on energy management programs.

4.13.7.2 Cogeneration and other heat recovery methods. The purpose of all heat recovery methods is to use available heat energy that might otherwise be wasted. Cogeneration is the production of electrical power and some other use of heat from a single fuel consumption process. Fuel-consumption efficiencies, normally in the 50-percent range, can be raised to approximately 80 percent. Cogeneration is addressed in both volumes II and III of this handbook. Heat recovery is accomplished by heat exchangers that transfer heat energy from one media to another. Efficient furnaces and boilers use heat exchangers to minimize heat lost through exhaust. Heat produced by industrial equipment, such as large computers, can be recovered and applied for useful purposes.

4.13.7.3 Energy efficient construction. Heating and cooling loads can be minimized by using architectural designs, building materials, and construction techniques that are matched to the local features of the site. Structures can be oriented to control and exploit the effects of solar radiation. The effects of prevailing winds can be controlled by building orientation and use of trees. Improved insulation of building surfaces reduces unwanted heat gains and losses in controlled spaces. Blast-hardened structures offer many opportunities for energy savings. DoD facility planners should ensure that energy-efficient and state-of-the-art materials and techniques are identified and evaluated for possible use in both new and retrofit construction.

4.13.7.4 Efficient HVAC equipment operation. Energy consumption can be significantly reduced by operating HVAC equipment only when required. HVAC equipment performance should be integrated, so that outputs do not conflict and waste energy through unnecessary adjustments. For example, excessive cooling can require reheating and dehumidifying of conditioned air. Building energy loads are reduced by operating equipment in economizer cycles. In these techniques, cool outside air (on cold days and at night) is brought in the building for cooling. The supplemental use of cool, outside air reduces the expense of operating refrigeration equipment. The use of off-peak operating cycles reduces the amount of heated or cooled air supplied to spaces that are not occupied or in operation. These energy-saving techniques add to the complexity of the control function and may not provide the precise control of indoor conditions required by sensitive electronic devices.

4.13.8 Environmental system upgrade planning. The most important aspect of environmental system upgrade or retrofit planning is conceivably in the original designing of the building. Good facility planning includes provisions for anticipated changes in mission requirements. Buildings should also be designed with associated changes in future environmental-control requirements in mind. Building space allocated to HVAC equipment should be of sufficient size and flexibility to accommodate future changes and upgrades. The planners should be familiar with the direction and trends of the HVAC industry, so that environmental-control space can be adapted to new equipment without the requirement for major construction. Replacement HVAC equipment should be selected on the basis of its economic operation, maintainability, and demonstrated reliability, as well as its being state-of-the-art.

4.13.9 Future environmental control trends which may impact DoD communications and data processing facilities. Energy management and life-cycle-cost analysis programs are finding common application, especially in large installations. New equipment and systems are being developed to operate more efficiently, which is stimulating research of new materials and technologies. The greatest improvements in environmental control are probably reflected in new computer-based monitoring and control devices. Designers and engineers must, however, be careful not to confuse state-of-the-art technology with short-term fads.

4.13.9.1 Energy management. Future environmental-control systems will be managed with programs at monitor and analyze energy consumption and life-cycle costs. These programs provide an instant picture of both current and projected energy costs. The information received can be used to verify the performance of installed systems and to indicate the need for replacement and upgrade. Volume III of this handbook contains detailed information on energy management programs.

4.13.9.2 Computers and environmental control. The speed and accuracy of computerized devices are improving both the design and operation of environmental control system. An expanding selection of supporting software will continue to be developed to help with the choice and configuration of HVAC equipment and materials. The calculation of heating and coolin loads can be greatly facilitated with the computer. Through computer modeling, the use of alternative HVAC equipment can be evaluated in terms of anticipated life cycle costs. Automated monitoring and control techniques will find increasing application, 4.13.9.3 New technologies. Reducing the consumption of nonrenewable fuels and increasing the use of renewable resources should continue to be the primary goals of developing HVAC technology. Fuel-burning furnaces and boilers are being made more efficient by such innovations as pulsed burning, exhaust-heat recovery, and improved materials. Increased use of normal storage will reduce the consumption of energy resources for both heating and cooling. The importance of heat mass and fenestration will be given more attention in building construction. Substances which store and release large amounts of heat during chemicai reactions, or changes in physical state, will find increasing application in HVAC. Meeting the increasing demand for cooling will be aided with the use of supplemental systems, such as ice bank storage.

4.13.9.4 New materials. Construction and HVAC materials will continue to improve. Stronger and lighter materials permit greater efficiency and innovation in architectural design. Improved insulating materials mean tighter buildings with less unwanted heat gains and losses, but an increased potential for reduced indoor air quality. Fiber-optic devices will distribute natural light to interior buildings aces, reducing the demand for energy-consuming and heat-producing artificial lighting. Fiber-optic devices will technology will also be applied to control functions, offering greater reliability and reduced vulnerability to electrical transient problems. Superconducting substances now being researched will revolutionize power distribution and control circuitry.

4.13.9.5 New equipment. HVAC equipment will continue to be improved as efforts to reduce fuel consumption are pursued. New equipment will be smaller, cleaner, and more efficient. Use of solar energy for heating and cooling will be expanded. Heat recovery applications will grow as improved heat exchangers are developed. Continued public concern over pollution will drive the development of improved ventilation and filtration equipment. Finally, the use of computerized devices for the design and operation of environmental control systems will become commonplace.

4.14 Electromagnetic interference (EMI) and electromagnetic compatibility (EMC). Power systems for the DoD should be designed to prevent electromagnetic interference. The power systems should comply with applicable Class A3 and C2 requirements contained in MIL-STD-461. The presence of EMI from one electronic source may adversely effect nearby equipment, thereby affecting EMC.

4.14.1 U.S. EMI/EMC standards. For DoD conformance with EMI/EMC standards, MIL-STD-461 and -462 are applicable.

4.14.2 Foreign EMI/EMC standards. DoD systems operating in a foreign country may face more stringent standards than those of the U.S. Some of the most common foreign standards such as Verband Deutscher Electrotechinker (VDE), Voluntary Control Council for Interference (VCCI), and International Special Committee on Radio Interference (CISPR) are discussed in para 5.13 of volume II of this handbook.

4.14.3 Methods of compliance. Methods of compliance are discussed in volume II of this handbook. (Ref. Vol. II , paragraph 5.13.)

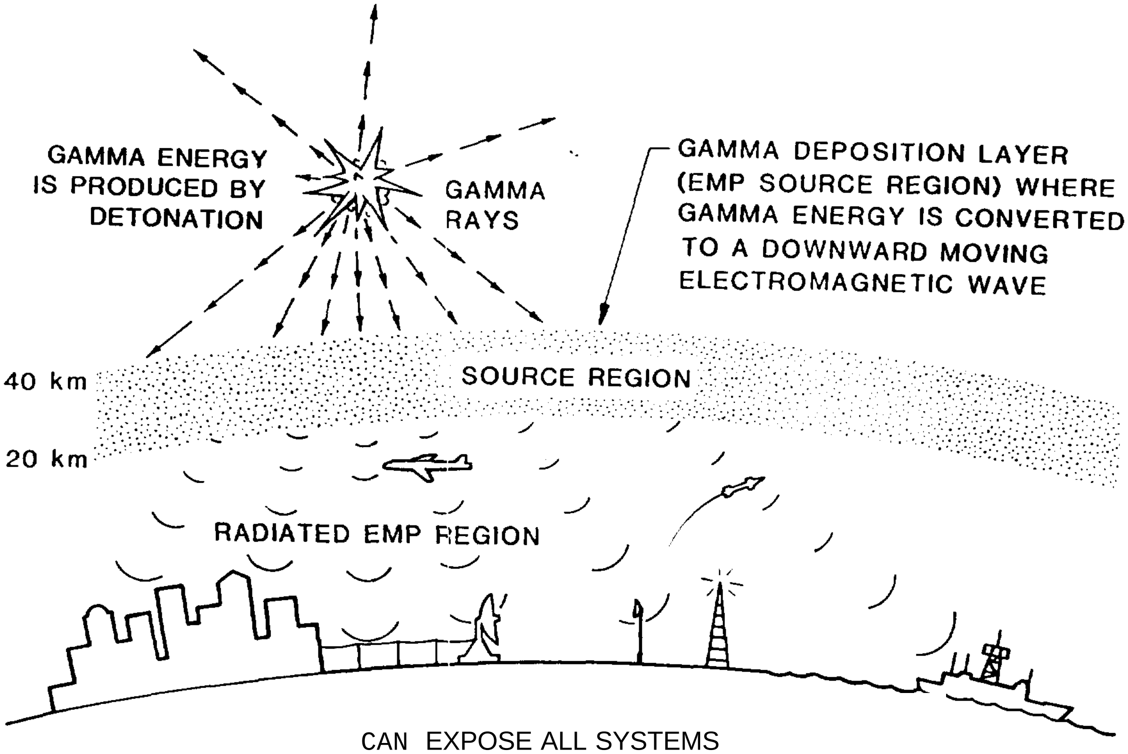
4.15 Transient voltage protection. Transient voltage protection of communications-electronics equipment is becoming more difficult as circuit components become more senitive. Integrated circuits have susceptibility to damage at transient levels smaller than that of discrete transistors, which are more susceptible than vacuum tubes. To cope with these transients, power conditioning may be an additional requirement at DoD installations where quality of power is not satisfactory. Such conditioning ranges from filters, capacitors. surge suppressors to isolation transformers, motor generator sets, voltage regulators and complete UPS.

4.15.1 Lighting. The Lighting Protection Code, NFPA NO. 78-1977, issued by the National Fire Protection Association contains the base requirements for protection of structures against fire, explosion damage, and for minimization of personnel hazards in the event of a lighting strike. NFPA NO. 78 requirements are not adequate to protect electrical distribution systems, signal and control cables, or electronic equipment from impulses produced by either direct or indirect strikes. In addition to the basic protection advocated by NFPA NO. 78, supplemental steps should be taken to protect the sensitive electronic equipment. A grounding and lighting protection study which demonstrates the effectiveness of the designed lighting protection system for a facility should be completed in accordance with individual service standards and included in the design analysis of the DoD facility. See also MIL-STD-188-124.

4.15.2 Switching transients. If not properly treated, switching transients will cause severe problems in C-E equipment at DoD facilities. Switching transients are caused by rapidly changing conditions occurring in a circuit during the interval between closing of a switch (or a contact and settling to steady-state conditions. Treatment of switching transients is covered in detail in para 5.5.6.7 of volume II of this handbook.

4.15.3 Electromagnetic pulse (EMP) and high-altitude electromagnetic pulse (HEMP). This discussion on EMP is intended to provide a basic understanding of EMP terminology and protection methods. Managers and engineers requiring detailed information on EMP protection for a specific mission or site should refer to UOIJ or individual service publications. One publication od this type, which also lists individual service EMP references, is DCA Instruction 350-175-1, Design Practice for High Altitude Electromagnetic Pulse (HEMP) Protection (being replaced by MIL-STD-188-125 and MIL-HDBK-423).

4.15.3.1 EMP survival requirements. Certain DoD facilities will be required to survive high altitude EMP (HEMP), and some may also be required to survive surface or air-burst nuclear effects (includes blast, shock, “thermal, and radiation). Depending on the stated survivability requirements for a surface or air-burst nuclear environment, facility EMP protection against the low-altitude threat will usually exceed that required for HEMP. In any event, the level of EMP protection against air and surface nuclear bursts must be in balance with the design capability of the overall facility to withstand other nuclear effects. Figure 32 illustrates the widespread coverage expected from HEMP.



CAN EXPOSE ALL SYSTEMS
WITHIN LINE OF SIGHT

FEATURES OF HIGH-ALTITUDE EMP (HEMP)

- WIDE AREA COVERAGE
- HIGH FIELD STRENGTHS (50 KV/M)
- BROAD FREQUENCY BAND (10 KH_z - 100 MH_z)
- ABSENCE OF MOST OTHER NUCLEAR WEAPONS EFFECTS

FIGURE 32. Expected HEMP coverage.

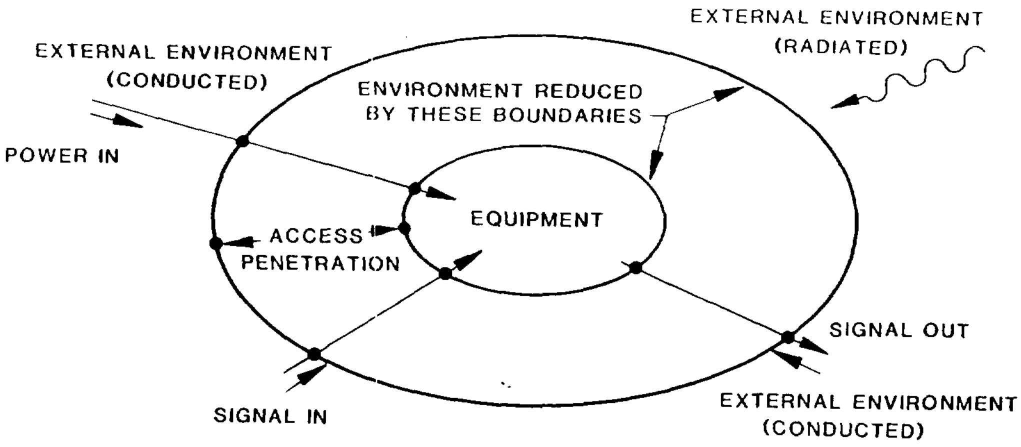
4.15.3.2 EMP effects compared with lighting.Because the nuclear HEMP arrives at the earth's surface as a plane wave rather than as a stroke channel, the melting, charring, and splintering effects associated with direct lightning strikes do not usually occur with the EMP. The EMP exerts its influence through induced effects; that is, the very large electromagnetic fields of the EMP induce large voltages or currents in antenna-like elements of equipment or structures.

4.15.3.3 EMP effects on power and communications. The primary effect of the EMP is, therefore, the production of large voltages or currents in conductors such as powerlines, buried cables, antennas, etc. These induced currents and voltages may then cause secondary effects, such as insulation flashover and electronic component damage or malfunction. Logic circuits, in which information is transferred as a train of pulses, are particularly susceptible to transients of the type induced by the EMP. Even small transients in these circuits can cause a false count or status indication that will lead to an error in the logic output, and large transients can destroy the junctions of solid-state components used in these circuits. Furthermore, the techniques used to protect equipment from the slowly rising lighting transients are not necessarily effective against fast-rising EMP-induced transients.

4.15.3.4 EMP hardening objectives. The main objective of all EmP hardening is to prevent the transient produced by a nuclear detonation from causing a system malfunction that degrades mission performance. Previous discussions have concentrated on the application of discrete protectors against the effects of EMP; however, the only completely effective method uses a barrier or topological scheme. A topological boundary system, such as illustrated in figure 33a uses electromagnetic shields, transient suppression devices, and isolation elements in harmony for assurance that the mission will not be degraded during EMP conditions.

4.15.4 Use of shielded enclosures in transient protection. If a facility is completely self-contained as shown in figure 33b, with no connection to outside communications, power or other utilities, then a Faraday cage offers the ultimate protection for electronic equipment. The "real-world" does not lend itself to this approach; therefore, some form of external metal shielding is required for military systems that must survive nuclear effects. This external surface may be integrated in the building walls of a communications facility, the skin of a missile, or the equipment cabinet itself. The exterior surface serves to divert currents present on penetrating conductors and to reflect or attenuate impinging electromagnetic radiation. Table XIII lists the performance of some typical shielded rooms. Some form of a shielded room or cabinet must be used at every DoD facility that is required to survive the effects of EMP. Volume II of this handbook places emphasis on the integrated design of shielded enclosures for a facility and includes basic concepts of shielded-enclosure performance and selection.

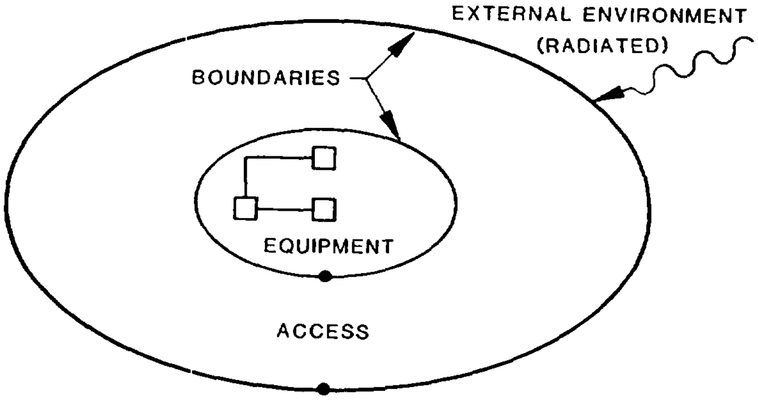
4.16 Grounding, bonding, and shielding (GBS). These topics are discussed, as appropriate, in paragraphs 5.5.6.5 and 5.5.6.7.6 through 5.5.6.7.8.2 of volume II of this handbook. Additional information is contained in MIL-STD-188-124 and MIL-HDBK-419.



PENETRATION TREATMENT IS PART OF BOUNDARY

- A "COMMUNICATIONS CENTER"
  - EXTERNAL POWER
  - RECEIVES/SENDS MESSAGES ELECTRONICALLY
  - UTILITIES (WATER, SEWAGE, TELEPHONE) PENETRATE

A. MOST SYSTEMS APPEAR LIKE THIS



- AN "ANALYSIS CENTER"
  - COMPUTER GENERATES PAPER REPORTS
  - EQUIPMENT POWERED BY BATTERY
  - ACCESS DOORS CAN BE MADE ALMOST CONTINUOUS WITH STRUCTURE

B. RARELY LIKE THIS

FIGURE 33. Generalized topological protection.

TABLE XIII . Typical shielded enclosure performance.

Room description	Frequency (kHz)	Magnetic shielding effectiveness (dB)	
		(Max.)	(Min.)
Copper screen cell	15	61	56
Styrofoam core, sheet metal skin	200	97	96
Hollow core, sheet metal skin, piano hinge, finger stock on door	15	100	81
	200	118	108
Sheet metal bonded to plywood, double finger stock on door	1000	100	80
Steel with folded and soldered seams, double finger stock on door, filtered power lines	14	58	34
	280	75	58
Continuously soldered sheet metal with zinc electroplate, commercial fingerstock, filtered power lines	14	70	65
	100	--	90
Inert gas-welded sheet steel with double finger stock	14	90	74
	200	130	106
Double shielding - continuous inert gas-welded low-carbon sheet steel with expanding panel siding doors	0.1	--	25
	1		62
	15	1%	92
	100	120	107
Partitioned room - continuous seams, intert gas-welded sheet steel with triple finger stock	0.15	104	73
	1.0	122	--
	5.0	80	--
	15	20	--

4.17 TEMPEST requirements (general). TEMPEST requirements will not be addressed in MIL-HDBK-411B. For information pertaining to RED/BLACK application, refer to NACSIM 5203 and MIL-HDBK-232. The information contained in this handbook (MIL-HDBK-411B) should be supplemented with guidance contained in NTISSI-No. 5203, and MIL-HDBK-232 for power and environmental control in TEMPEST facilities. Note: To determine if the NACSIM 5203 guidelines are applicable, refer to NACSI 5004.

4.18 Fixed fascility design criteria. This section is concerned with the desiqn and construction features of buildings that are unique or of special significance to DoD communications and data-processing activities. The primary goal of a building design is to provide an operating environment which maximizes the reliability, survivability, and long-term economy of the mission equipment systems. Of paramount importance is the protection of mission equipment against failure and damage caused by other systems. The protection of power-sensitive devices against electrical transients is given special attention in volume II,

4.18.1 Standard floor plan. The standardization of mission equipment floor plans is often required for operating, maintenance, or training reasons. Buildings and their supporting electrical power and environmental control systems need not be standardized; rather, they should be designed and operated according to the climate and geographical features of their locations. These features are identified in the site survey.

4.18.2 Inside environment. A building design must provide access and space for both known and anticipated future-mission and supporting equipment. DoD facilities have unique access requirements for power and signal cablin , as well as environmental control networks of ductwork, piping, and control circuitry. Improper planning that results in last minute “quick fixes” and add-ons often creates interference problems among the various mission and support systems being operated.

4.18.2.1 Ducts for communications. A major communications concern in the design of a new installation is that usable cable trays, trenches, and ducts, with adequate growth potential, are provided. The number, and type of construction, of building-entry points are controlled by military department rules. Building and room-entry points should be sealed against the infiltration of unconditioned dir into controlled spaces, especially critical areas housing computers or other sensitive electronic devices. The configuration of cable trenches and ducts should accommodate planned mission equipment with a reasonable potential for growth and changes. Concrete slab floors may incorporate equipotential planes, which conform to MIL-HDBK-419 and volume II of this handbook. Similarly, bonding of cable trays (normally to building steel) should also be accomplished in accordance with military department practices. See volume II for additional information concerning GBS.

4.18.2.2 Raised floor considerations. Raised floors, which are sometimes called access floors, are commonly installed in computer rooms to facilitate the distribution of cabling. Raised floors commonly incorporate special GBS features, such as equipotential planes and bonding procedures. The area under raised floors is sometimes used as a plenum for the distribution of conditioned air, but there are reservations. Special care must be taken to ensure that the environmental integrity of the under-floor space is preserved. The under floor area should be sealed against the entry of untempered air through cable or other utility entry points. blowers or fans needed to move supply air from the under-floor area into the conditioned spaces or equipment cabinets can use more energy than above-floor systems.

4.18.2.3 Ducts for power distribution. Power system distribution is addressed in volume II of this handbook.

4.18.2.4 Utility distribution. Ductwork and pipe systems for the distribution of air and water are normally installed in accordance with building criteria of the respective military department and local building codes. Building criteria and codes are concerned with personal health and safety, building protecting, and the conservation of energy. It is becoming more common to adapt architectural designs to accommodate building utility systems, rather than fitting utilities into available space. The security and GBS aspects of utility distribution systems are also addressed in DoD facility planning.

4.18.3 Outside environment. Installations designed to house DoD facilities have special construction features which are required to support mission activities.

4.18.3.1 Normal construction. Basic construction criteria are contained in DoD 4270.1-M, Construction CRITERIA Manual. Permanent concrete-and-steel-frame DoD buildings are designed for a life cycle of 25 years. Semipermanent buildings have a life cycle of 5 to 25 years. Because of security requirements, most communications and ADP buildings have a limited number of doors and windows. The military departments prescribe construction criteria and standards for structures on their installations.

4.18.3.2 Hardened construction. Buildings are hardened in accordance with survivability criteria and threat assessments. Hardening a building against blast effects can be accomplished by increasing the strength of structural elements and adding the protection of earth sheltering. Hardened facilities have unique heat-transfer characteristics that may be exploited for environmental control purposes. For example, reinforced walls can have high insulating qualities and underground structures can have favorable indoor temperature-control characteristics. The physical location of conditioned spaces in hardened structures is important to environmental control. Life safety is also a major design consideration.

> NOTE: Both reinforced concrete and earth-sheltered construction offer the possibility of improved shielding for sensitive electronic equipment.

Individual military department criteria for hardened construction should be reviewed to determine the shielding effectiveness (SE) that can be achieved. Volume II of this handbook provides additional information on SE.

4.18.3.3 Shockj mount isolation. Shock mounting is used to provide protection against blast damage and to reduce the adverse effects of noise and vibration. Reducing the effects of noise and vibration can improve the operating environment of both equipment and personnel. This can be very significant during periods of sustained operations. Figure 34 is an example of an equipment shock mount with required bond.

4.18.3.4 Nuclear, biological, chemical (NBC) considerations. In geographic areas where the threat of an NBC attack is high, facilities should be protected. In addition to shielding and transient protection, appropriate filters should be used for all air conditioning and ventilation apertures. Consult individual service documents for the method of providing such treatment.

4.19 Fcility integration. The concept of energy conservation is distributed throughout this handbook. Figure 35, although complicated, expresses this concept. This particular design was driven by the widening gap between demand and usage charges for utility power. The design in figure 37 uses ice storage, several heat recovery units, and shifts daytime HVAC utility demand to off-peak hours or to the on-site cogenerator. This design also uses the same piping that distributes HVAC chilled water during normal operation to supply the fire sprinkler under emergencies. As building users struggle to control energy costs that include heavy penalties for high daytime power usage, practical methods of shifting some of the load to off-peak hours will continue to be sought.

4.19.1 Power and signal line integration. A major factor which must be considered when designing a facility is the integration of ower and signal lines. Improper design and installation practices may result in impaired operation of sensitive electronic equipment due to the electromagnetic effects of noise generated by electrical power circuits. Signal lines include those lines used for communication circuits, data processing systems, alarm circuits, environmental control systems, and monitor circuits.

4.19.1.1 Signal line shielding. All signal lines should be shielded by using shielded cable, conductive conduit, or conductive duct. The type of shielded cable to be used for signal lines should be in compliance with the manufacturer's specifications, since the effectiveness of the shield may be dependent on the operating frequency of the equipment. All cable shields, conduits, or ducts should be grounded in accordance with MIL-STD-188-124 and MIL-HDBK-419.

4.19.1.2 Signal line isolation. Signal lines must be isolated from power lines and noise-generating devices. All signal lines which are close to power circuits should be parallel with them and should be separated by a minimum of 6 inches (15 cm). Where signal lines must cross power lines, they should cross at 90 degrees and should be separated by a minimum of one inch. Crossovers of less than 90 degrees should be avoided. Since fluorescent light ballasts generate electrical noise, signal lines should be separated from them by the maximum possible distance. It is a good practice in

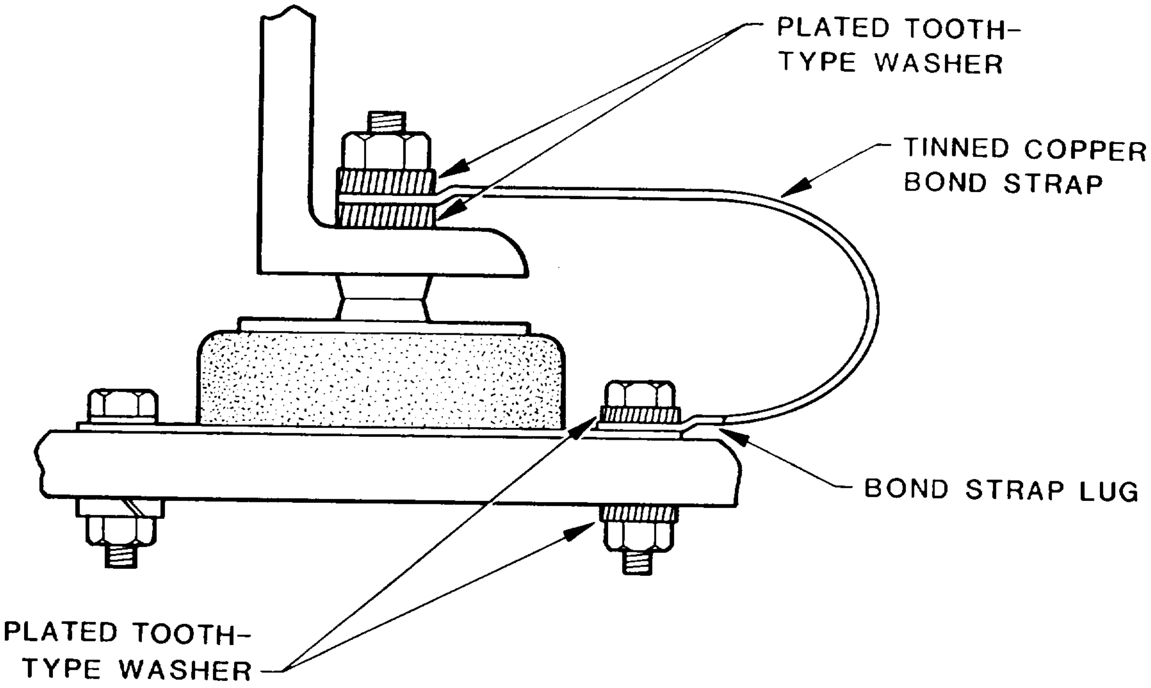
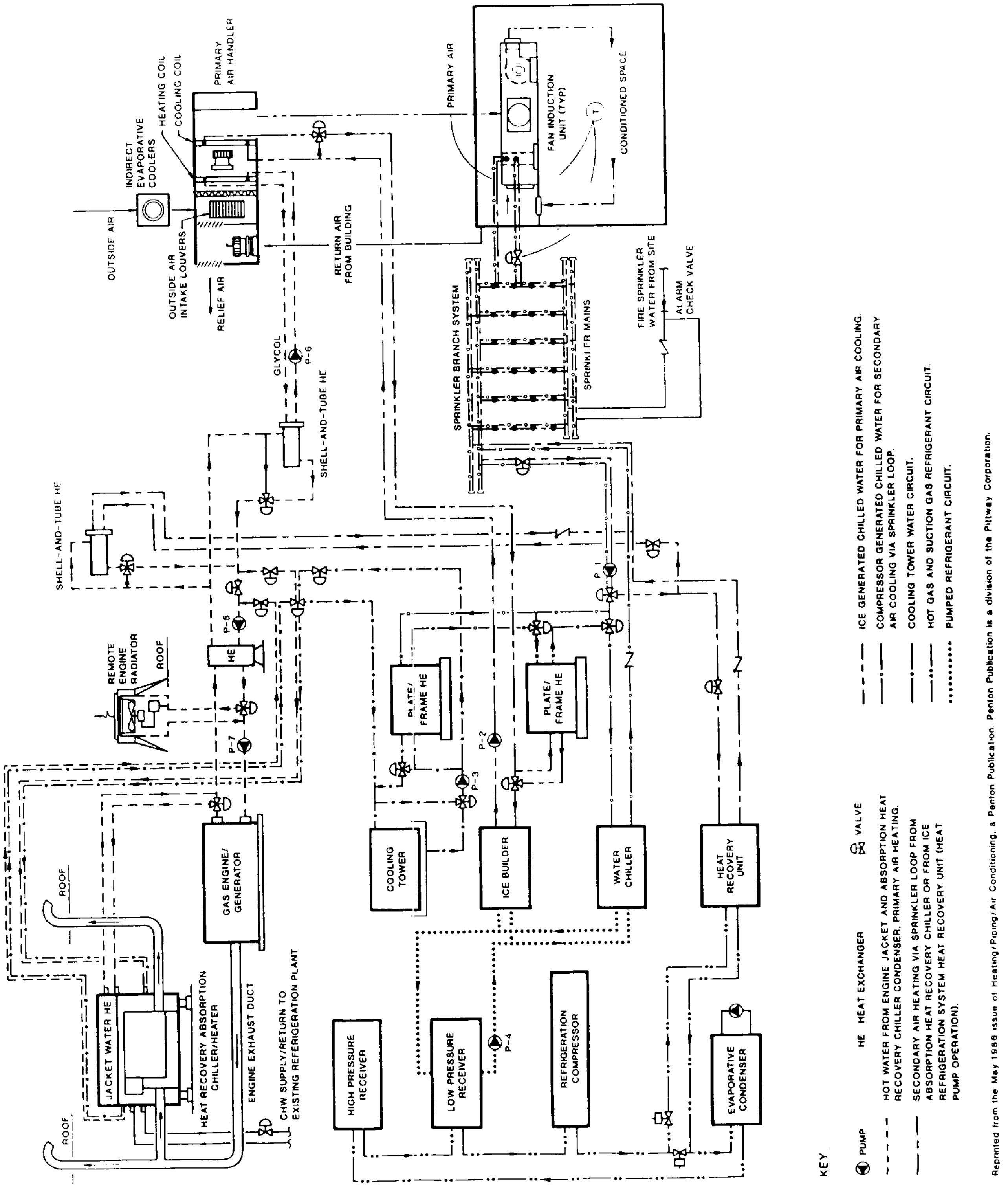


Figure 34. Bonded equipment shock mount



Reprinted from the May 1986 issue of Heating/Piping/Air Conditioning, a Penton Publication. Penton Publication is a division of the Pittway Corporation.

FIGURE 35. Integrated ice storage/sprinkler/cogeneration/HVAC system diagram.

facilities using a raised floor for signal lines to be installed under the floor to reduce the effects of fluorescent lighting. Electric motors are also causes of electrical noise. When motors must be operated close to sensitive electronic equipment, they should be adequately shielded and filtered to reduce or eliminate electrical noise. The use of a separate power feed for electric motors is recommended.

4.19.1.3 Transient voltage protection. Signal lines,especially those that penetrate the external facility walls, should be provided effective transient-voltage protection. Internal lines may also require protection from internally generated transients due to motors and appliances turning on or off and cycling of airhandling systems. Signal-line transient protection should be as effective as the protection provided for power lines.

4.19.2 Environmental control system balance. The environmental control system of a facility is composed of various types of HVAC equipment. supporting large installations, with closely controlled indoor environments, can be very complex. In a properly designed system, HVAC equipment operates in an integrated manner so that the output of individual devices will not interfere with, or be counter to, the performance of the others. Counterproductive performance results in incorrect indoor conditions and wasted energy. For example, excessive cooling may require the addition of heat or humidity in a space to maintain design conditions. Similarly, excessive amounts of raw outdoor ventilation air require energy for conditioning. The demands placed on environment control systems vary over time, as mission operations change, HVAC equipment ages, and control procedures are violated. System-performance monitoring and reporting should be a continuing effort.

4.19.3 Integrated control of mission support elements. Several mission support functions for DoD facilities lend themselves to assignment to an integrated control console or panel. For example, fire detectors, HVAC, and emergency generator indicators, security light control, CCTV (monitoring building security and operation of control valves, etc.), and power quality monitors are all likely candidates for integrated control. Integrated control not only saves manpower but also decreases reaction time during multiple emergencies.

5. DETAILED REQUIREMENTS

Not applicable; see volumes II and III.

6. NOTES

6.1 Intended use. The purpose of this handbook is to provide basic guidance to managers and engineers of the military departments and agencies in the design and installation of power and environmental control systems at DoD fixed conanunications and related automatic data processing facilities.

6.2 Subject term (key word) listing.

air cleanliness
air conditioning
air quality
arresters
attenuation
conditioned air
conditioned space
cooling
cooling coil
cooling load
cooling systems
design conditions
direct digital control
ducts
electric utilities
environmental control
environmental engineering
fault current
fenestration
heat gain
heating
heating load
heat loss
heat transfer
humidity
one-line power diagrams
power amplifiers
power factor
power lines
power loss
power measurement
power transformers
suppressors
temperature

temperature control
transients
variable air volume
ventilation
voltage gain
voltage sags
voltage suryes
waste disposal

6.3 Changes from previous issue. This revision correlates to the previous issue in concept only. The content has been subjected to extensive change and reorganization to reflect emerging technology. Asterisks or vertical lines are not used in this revision to identify changes with respect to the previous issue due to the extensiveness of the changes.

Custodians
  Army - SC
  Navy - EC
  Air Force - 90

Review activities
  Army - CR,CE
  Navy - YD,MC
  Air Force - 50
  DoD - DC, MP

Preparing activity
  Army - SC

(Project SLHC-4112)

ALTERNATING CURRENT (ac) THEORY, POWER USAGE DATA COLLECTION, AND USEFUL CONVERSIONS

10. Scope. This appendix provides a brief review of alternating current (ac) theory as well as a method to manually estimate ac power consumption and useful electrical /electronic/metric conversion tables. This appendix is to be used as a refresher only. For exact applications, a comprehensive text or individual military department technical publications should be consulted.

20. Applicable documents. This section is not applicable to this appendix.

30. Definitions. See paragraph 3.1 of this handbook.

40. Review of alternating current (ac) theory.

40.1 Elements. The ultimate particles of an element are called atoms. An atom consists of a small, relatively heavy nucleus with a number of lighter electrons circling it. The nucleus in turn is composed of protons and neutrons which, like electrons, are elementary particles that cannot be subdivided further.

40.2 Electric charge. Electric charge is a basic property of protons (positive) and electrons (negative). Charges of the same sign repel each other; charges of opposite sign attract each other. The number of protons in the nucleus of an atom normally equals the number of electrons around it; therefore, the atom as a whole is electrically neutral.

40.3 Electric current. The unit of electric charge is the coulomb (C). The charge on the proton is $+e$, and that on the electron is $-e$. A flow of charge from one location to another constitutes an electric current. A conductor is a substance through which charge can flow easily, and an insulator is one through which charge can flow only with great difficulty. Metals, many liquids, and gases whose molecules are electrically neutral are insulators. A number of substances, called semiconductors, are intermediate in their ability to conduct charge. Electric currents in metals consist of electron flow; such currents are assumed to occur in the direction opposite to that of electron movement. Since a positive charge moving in one direction is essentially equivalent to a negative charge moving in the opposite direction, this assumption makes little practical difference. Both positive and negative charges move when a current is present in a liquid or gaseous conductor. When an amount of charge (Q) passes a given point in a conductor in the time interval (t), the current (I) in the conductor is:

$$I = \frac{Q}{t}$$

$$\text{or current} = \frac{\text{charge}}{\text{time interval}}$$

The unit of electric current is the ampere (A), where:

$$1 \text{ ampere} = \frac{1 \text{ Coulomb}}{\text{second}}$$

Essentially, ac circuit analysis is performed in much the same manner as dc circuit systems. The notation to describe dc current and voltage, network theorems, and Kirchhoff's laws still apply. However, where simple algebra provides most solutions for dc circuits, higher levels of mathematics are required to find exact solutions to ac circuitry. The most sophisticated mathematics is required for ac study because ac currents and voltages vary with time, and this means additional circuit parameters besides resistance must be considered. When the driving voltage or current sources are fixed in magnitude and polarity, as in dc circuits, the only opposition offered to the flow of current is due to the circuit resistance (R).

40.4 Ac circuit characteristics. When the voltage source and/or current vary with time, even a short section of wire reacts in some degree to the following:

a. An opposition to the flow of current (resistance, R)

b. An opposition to the change in current (inductance, L)

c. An opposition to the change in voltage (capacitance, C)

40.5 Development of waveforms. A voltage or current plotted versus time is called a waveform. Figure A-1a, for example, is a plot of a constant dc voltage (e) versus time (t). If the dc polarity is reversed, we have the result shown in A-1b.

a. If a waveform reverses polarity periodically, it is referred to as an alternating current or voltage. If the switch in figure A-2a is moved periodically between positions A and B, the waveform in figure A-2b would result. Several of the commonly generated waveforms are illustrated in figure A-3. Parameters that are of particular interest when studying periodic waveforms are:

(1) Positive peak amplitude

(2) Negative peak amplitude

(3) Peak-to-peak amplitude

(4) Period

(5) Frequency

(6) Average value (dc component)

(7) Root-mean-square (rms) value

To understand the significance of these parameters, consider the example shown in figure A-4. In this illustration, +100 volts is the positive peak amplitude. It is important to realize that the peak positive amplitude of a waveform could be assigned a negative value if the entire waveform is below the zero axis.

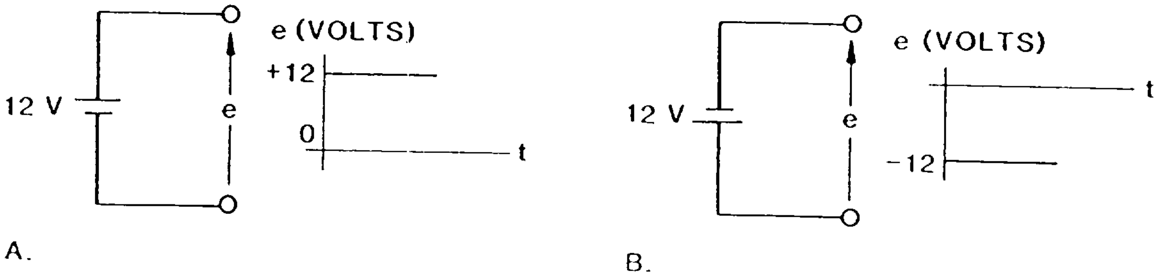


FIGURE A-1. Voltage plotted against time.

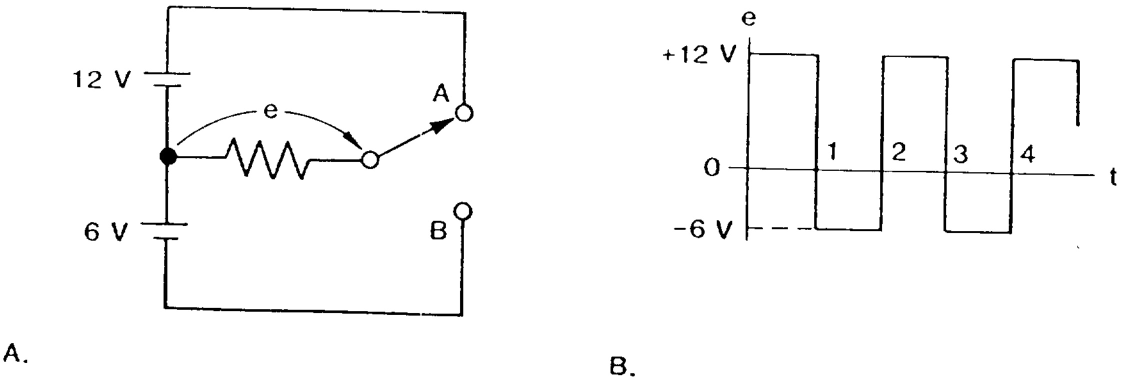


FIGURE A-2. Results of switched dc .

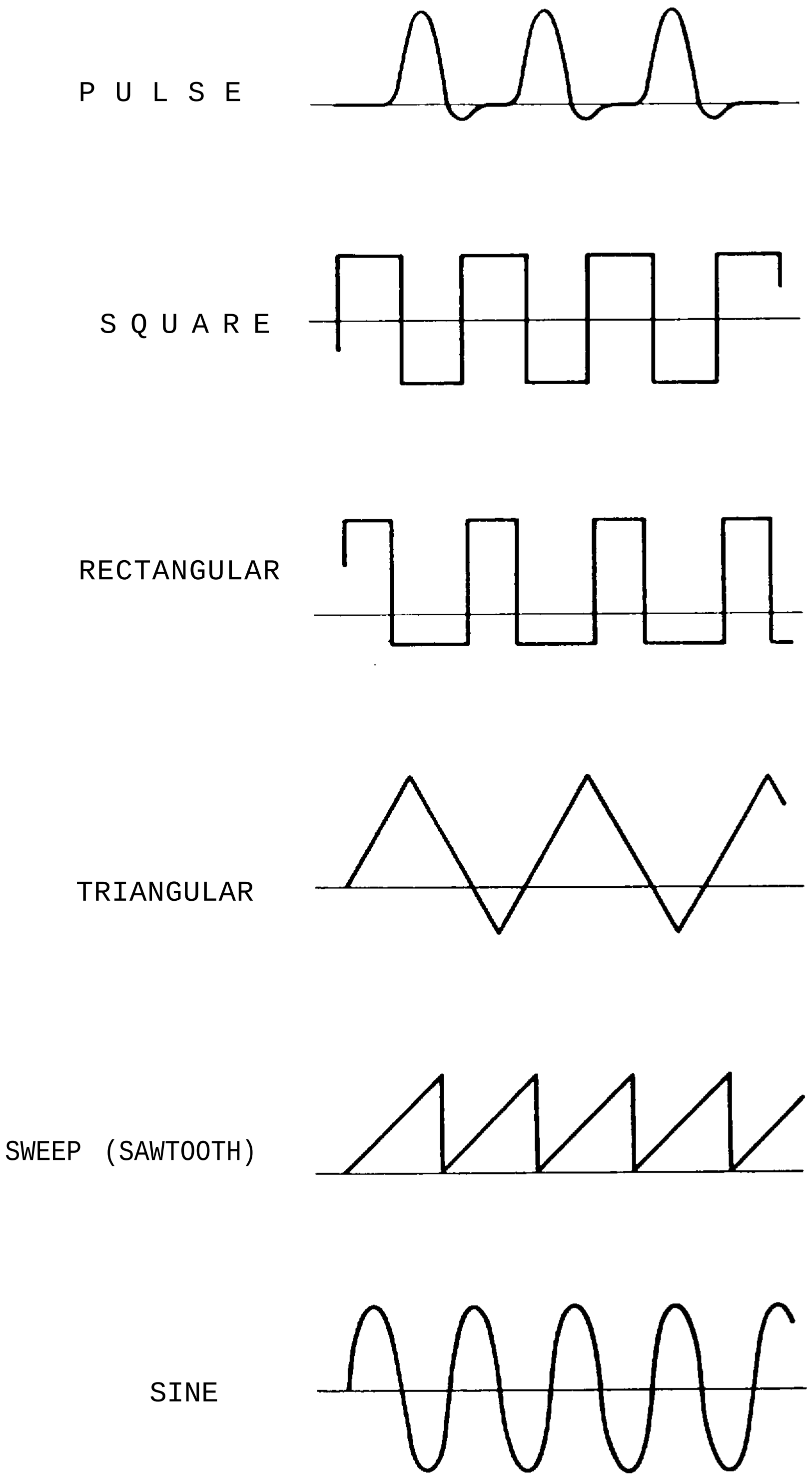


FIGURE A-3. Commonly generated waveforms.

The negative perk amplitude in figure A-4 is -120 volts. If all of a waveform lies above the zero axis the peak negative value will be assigned a positive number.

The peak-to-peak amplitude is the absolute value of the amplitude between the positive and negative peak amplitudes. Thus for figure A-4, the peak-to-peak (abbreviated p-p or pk-pk) amplitude is 220 volts.

The period (T) of a waveform is the length of time it takes to repeat itself. Thus in figure A-4 the period is T = 10 sec.

The frequency (f) represents the number of times the waveform repeats itself in a given time interval. If the time interval is equal to the period, the waveform has completed one cycle. Frequency and period are reciprocal quantities expressed by:

$$f = \frac{1}{T}$$

$$\text{and, } T = \frac{1}{f}$$

The hertz (Hz) is the international unit used to express cycles per second therefore:

$$1 \text{ Hz} = \frac{1 \text{ cycle}}{\text{sec}}$$

With the adoption of Hz as the international unit, the expressions 10,000 cycles/sec or 10 kilocycles/see (10 kc/s), become 10,000 Hertz or 10 kilohertz (10 khz).

g. The average value of some periodic waveform is its average value as determined over a time interval equal to the period T. The average value is the dc component of a waveform, and it represents what a dc voltmeter would read if it were driven by a voltage waveform. To find the average value of any function, say y = f(x), over some interval , as shown in figure A-5, it is necessary first to determine the area bounded by the curve (shaded area) during this interval and then to divide this area by the length of the interval. This yields the average valve. In figure A-5, some of the area is positive and some is negative. To obtain the net area, subtract the negative area from the positive. If the negative area exceeds the positive area, a negative average valve will result. Mathematically, the average value of a waveform is expressed as an integral:

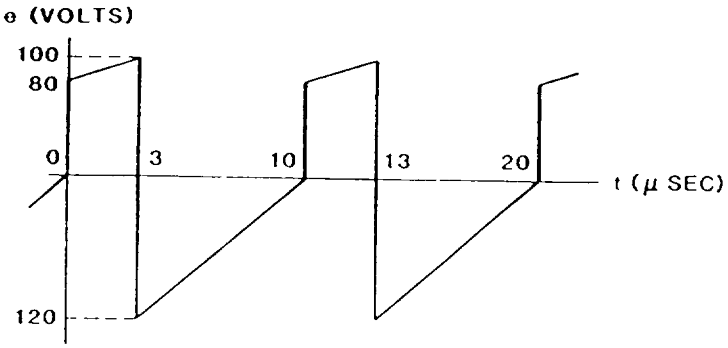


FIGURE A-4. Peak voltage generation.

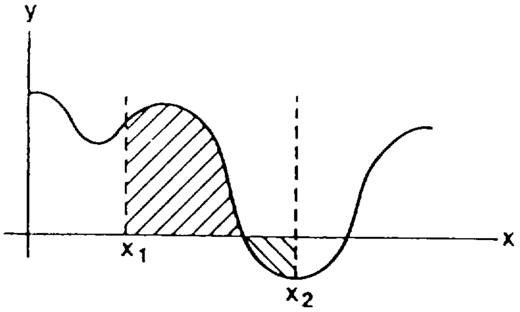


FIGURE A-5. Average waveform value.

$$\text{Average value} = \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} f(t)\,dt$$

where $t_2 - t_1$ is the time interval over which we seek the average value, usually equal to the period, and

$$\int f(t)\,dt$$

is a mathematical symbol used to designate the area under a curve (in this case a plot of some f(t), meaning function of time) over an interval $t_2 - t_1$. A simple interpretation of the integral is:

$$\text{Average value} = \frac{\text{the net area between the waveform and the time (t) axis during a given time interval}}{\text{the given time interval}}$$

h. The root-mean-square or effective value of a waveform represents developed power. For example, if some periodic voltage waveform is impressed on a resistor, the resistor will dissipate heat. This heat dissipation will occur even if the average value of voltage (or current) is zero. In this case, the direction of current flow does not matter - current flow through the resistor causes energy loss. By definition, the effective or rms value of a voltage (or current) waveform is that value which develops as much average power in the resistor and an equivalent dc voltage. To determine the rms voltage value of a waveform, the instantaneous power at any moment in time is given by:

$$P = \frac{e^2}{R},$$

where e is the instantaneous voltage across the resistor R.

i. There are two kinds of power we are usually interested in - instantaneous power (p) and average power (P). The instantaneous power for any waveform of voltage or corresponding waveform of current is given by:

$P = ei$

p = instantaneous power
e = instantaneous voltage
i = instantaneous current

The current and voltage waveforms need not be the same. In fact, most ac circuits display leading or lagging currents and voltages. To determine average power in any device, and with e and i waveforms, generate the p curve by the P = ei equation, and then determine the average value of the p curve in a manner similar to the average voltage or current method discussed above. For a waveform of period T,

$$p = \frac{\text{area under the p curve during the interval T}}{T}$$

The average and rms values of a waveform will not be the same, therefore, rms rather than average voltage or current values is used when computing power.

40.6 Power generation. The most common form of electric power is produced by generators which convert mechanical energy to electrical energy. Most of these generators develop an alternating voltage (and current) with a waveform that closely resembles figure A-6. Because this type of waveform is based on a trigonometric function called the sine, it is referred to as a sine wave or a sinusoid.

40.7 Voltage. In order to make current flow through a conductor, an electrical pressure is required to separate the electrons and protons. electrical pressure (also called the electromotive force or the potential difference) is known as voltage, and the basic unit of measure is the volt.

40.8 Constant potential systems. The most common type of system for electrical distribution is the constant potential type where the voltage is kept as constant as possible and the current varies with variations in the load. This system is further subdivided into alternating and direct current.

40.9 Alternating current (ac) systems. Current in alternating current systems first flows in one direction around a loop of conductive material, then reverses and flows in the other direction at regular recurring intervals. Most power systems are of the alternating current type. To understand how this type of current is produced, a simple two-pole generator is described. Basically, this generator consists of a north and south magnetic pole and a loop of wire fixed so it can rotate between the poles as shown in figure A-7. As the loop rotates between the poles, a current is induced which flows in one direction through the first 180 degrees. induction of current occurs when the loop cuts the magnetic lines of force flowing from the north to the south pole. When the loop reaches the 90 degree point, the maximum number of lines are being cut and the induced current is at a maximum. When the loop reaches the 180 degree point, it is no longer cutting any lines of force and the current is zero. One complete revolution of the loop constitutes one cycle because the current has gone from zero to maximum value twice as shown in figure A-7.

40.10 Single-phase power. The current produced by this generator is single-phase because only one source of induced current (one loop or coil) is used between the poles. An electrical system can be identified by the number of wires and the voltage between the wires. For example, figure A-8 shows is single-phase, two-wire, 120-volt system. The notation for this system is 10-2W-120V. A single phase, three-wire, 120- /240-volt system would be shown as 10-3W-120/240V.

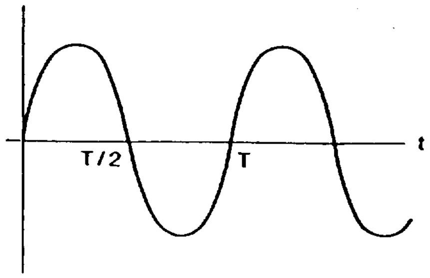


FIGURE A-6. Sine wave generation.

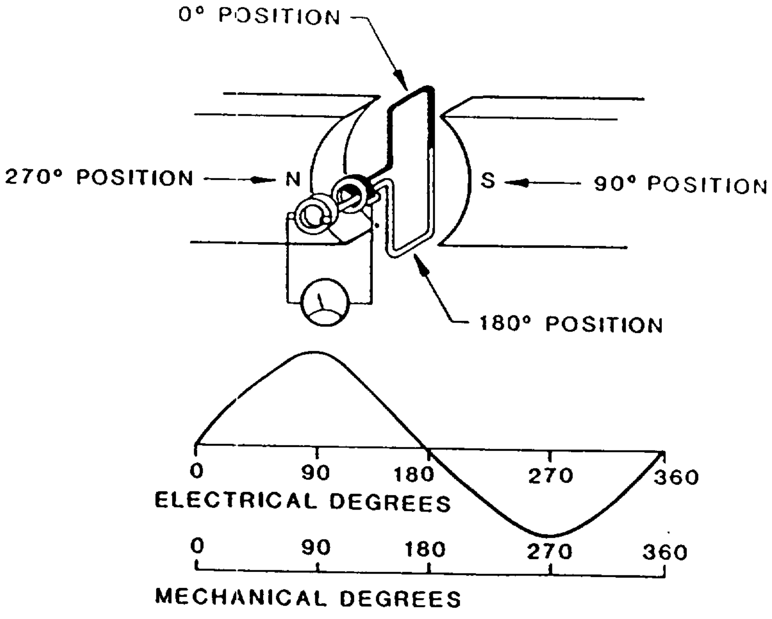


FIGURE A-7. Generator construction.

40.11 Two-wire systems (l0-2W). In the single-phase, two-wire system (figure A-8), one of the two wires from the generator is connected to ground and is called the grounded conductor or neutral. The other wire is called the phase conductor. Normally, the voltage difference between these conductors is 120 volts. In this system the current in one conductor equals the current in the other. Facilities that use single-phase current usually have very light electronic and lighting loads.

40.12 Three-wire systems (10-3W). In this system, there are two voltages available which provide the advantage of simultaneously obtaining a high voltage for heavy loads and a lower voltage for lighter loads. FIGURE A-9 illustrates the three-wire, single-phase system. In this particular wiring arrangement (called a wye), the voltage between the phase conductors is approximately twice the voltage between the neutral and either phase conductor. The current in the neutral (grounded) conductor is equal to the difference between the currents in the phase conductors. When the connected load between the neutral and one phase equals the connected load between the neutral and the other phase, the loads are balanced. Under this condition, the currents in the phase conductors are equal and neutral current flow is zero.

40.13 Three-phase power generation. If three coils (or loops) separated by 120 degrees are used, the current is induced in each one by the poles at a different time with the result shown in figure A-10. Note that the illustration shows a much smoother sequence of impulses than the earlier single-phase illustrations. Single-phase power has not become obsolete by the increased use of the three-phase concept as each type has its own specific application based on the type of load to be served.

a. As stated before, three-phase power is, in effect, generated by three precisely spaced single-phase coils. This system usually consists of four conductors although three conductor are sometimes used. Each conductor represents one phase. As the three-phase power is produced in the generator, one of two methods is used to connect the coils for distribution to the load:

The y (wye) or star connection
The Δ or delta connection

Normally the delta generator connection employs three wires and the wye employs four wires.

b. Three-wire sustems (30-3W). Figure A-II shows a three-phase, three-wire system using a delta connection. All three wires are considered phase conductors. Any 1O-2W, 240-volt load may be connected between any two-phase conductors. One of these phases may have a grounded center conductor brought out, if required, to serve a 1O-2W, 120-volt load. Provision for a 1O-2W, 120-volt load can also be made external to the generator by using a center-tapped transformer.

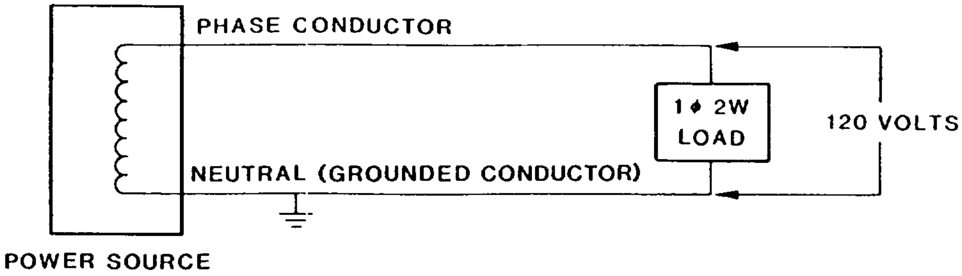


FIGURE A-8. Single-phase ac power.

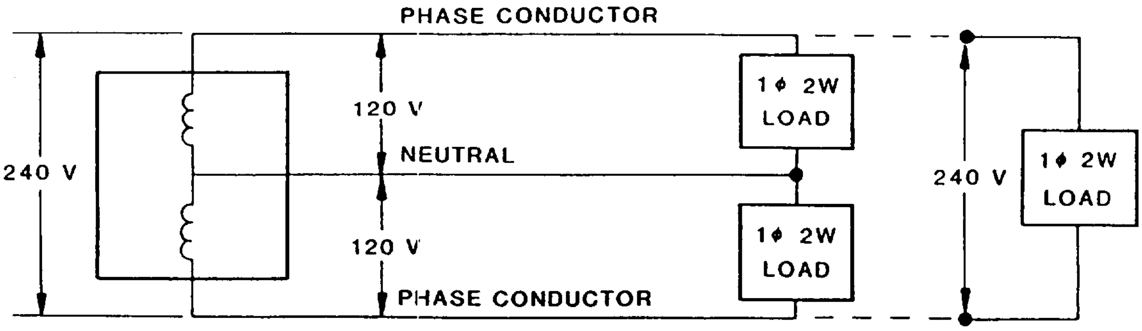


FIGURE A-9. Single-phase, three-wire ac power.

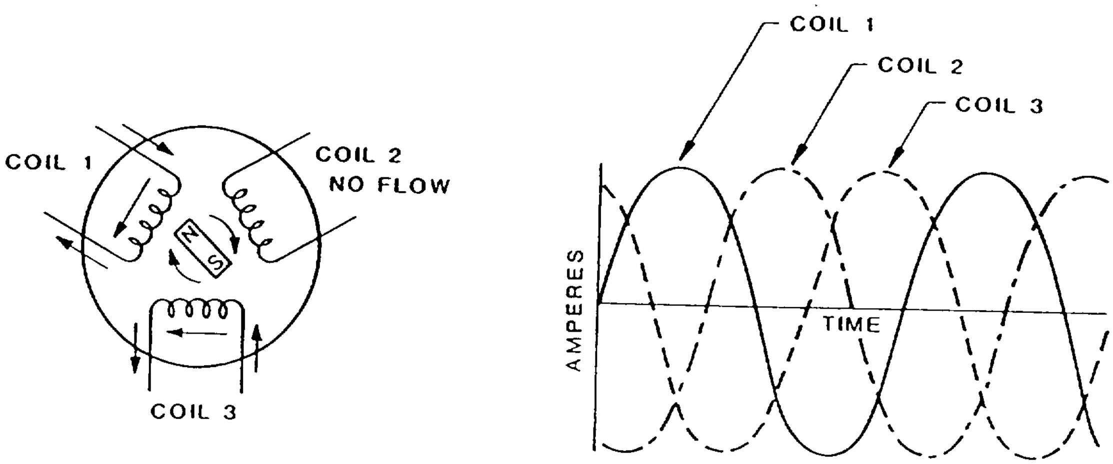


FIGURE A-10. Three-phase power generation.

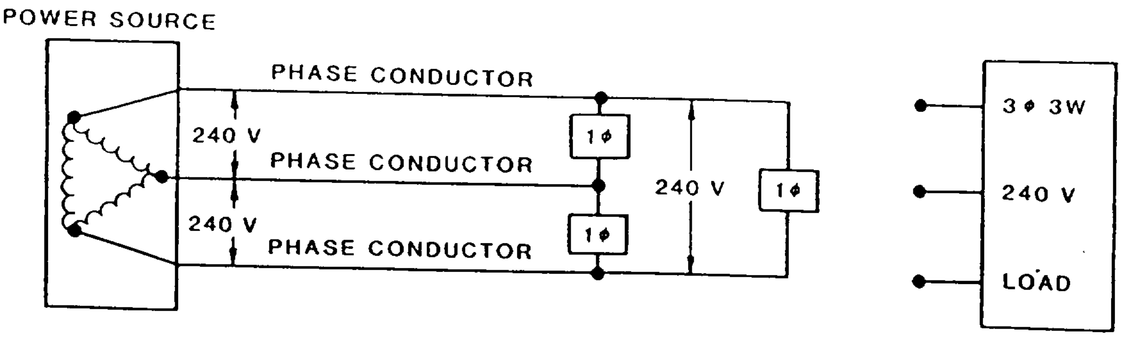


FIGURE A-11. Delta connected three-phase power.

c. Four-wire systems (30-4W). Figure A-12 shows a three-phase, four-wire system using a Y connection. There are two voltages simultaneously available from this system: phase-to-neutral voltage and phase-to-phase voltage. Note that the phase-to-phase voltage is equal to 1,73 times the phase-to-neutral voltage (208/120V). As in the single-phase system, the loads between the neutral and the phase wires should be balanced to reduce the current in the neutral to a minimum. Any 1O-2W, 120-volt load can be fed power by connecting it between any phase conductor and the neutral. Any 1O-2W, 208-volt load can be fed between any two-phase conductors. Any 30-3W, 208-volt load can be fed by connecting it to the three-phase conductors or any 30-4W, 120/208-volt load can be fed power by connecting it to any four conductors. The delta-based connection is seldom used on low-voltage power distribution systems. There are several reasons for this, such as higher voltages to ground and poorer suppression of unwanted harmonics. The wye system must also use a fifth conductor which is an equipment protection (green-wire) grounding conductor required by the National Electric Code (NEC).

40.14 Reasons for using ac power. One of the most important reasons for using ac power generation and distribution is that it can be readily changed by use of a transformer,. With a transformer, a particular ac or varying voltage can be raised or lowered to the value required by the load. A basic transformer is relatively uncomplicated, as shown in figure A-13. In this case, a conductor of particular type and size is wound around part of an iron core to form the input or primary side. Another conductor selected and sized to provide the desired output characteristics is wound on another part of the core for a secondary winding.

a. When a voltage (also referred to as electromotive force or emf) is applied to the primary side, magnetic lines of force are created that cut across the secondary winding and result in an induced secondary voltage. this action to continue, the voltage in the primary side must continue to change in value or reverse in polarity. When the voltage reverses, a voltage of opposite polarity appears in the secondary winding.

b. The ratio of the number of turns in the primary and secondary windings determine whether a transformer is a voltage step-up or step-down device. Since the primary and secondary power theoretically remains the same (except for such things as flux leakage and resistance losses), the secondary current must decrease as voltage increases or increase as voltage decreases. Transformers are required for load isolation and to match the voltages in the distribution system to those required by the load.

50. Power usage data collection.

50.1 DoD worksheets. DoD facility power system load tabulation worksheets may be used to estimate total power requirements and an estimate of backup or power conversion equipment loads. See figures A-14 and A-15.

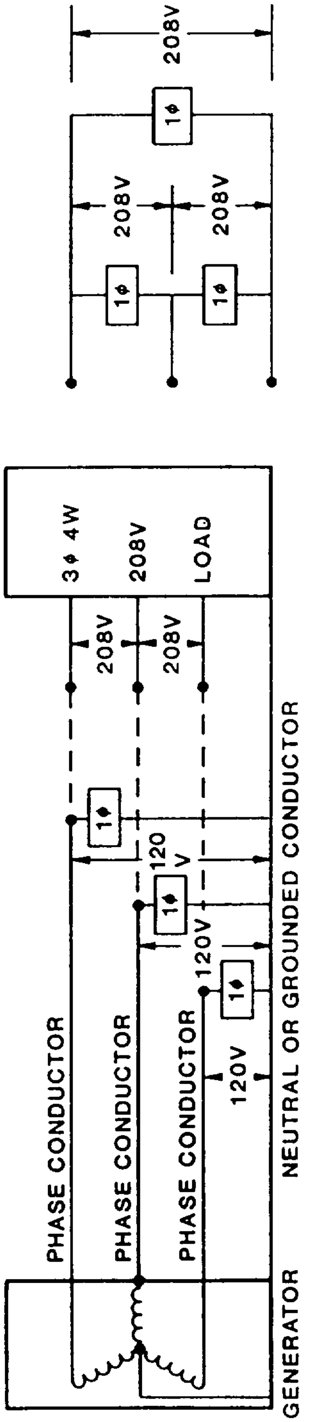


FIGURE A-12. Wye connected three-phase power.

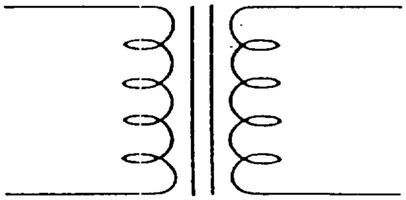


FIGURE A-13. Basic transformer configuration.

DoD FACILITY ELECTRICAL POWER SYSTEM LOAD TABULATION WORKSHEET*

FACILITY LOCATION ____________________

SUPPLY VOLTAGE __________ FREQUENCY ______ PHASE ______

SUPPLY SECONDARY TRANSFORMER CONNECTION DELTA ______ WYE ______

ITEM #	FUNCTIONAL DESCRIPTION OF STATION LOAD**	POWER FREQ REQ'D IF OTHER THAN 60 Hz	POWER HEIRARCHY DESIGNATION				BRANCH FEEDER #	PHASE		PHASES USED	TYPE OF BACKUP OR POWER CONVERSION EQUIPMENT REQUIRED (IN kW)						NOTES
			NO	NT	NCT	CT		1φ	3φ		1 NONE	2 ENGINE-GENERATOR	3 MOTOR-GENERATOR	4 STANDBY UPS	5 ON-LINE UPS	6 REDUNDANT OR PARALLEL UPS	
										TOTALS							TOTAL EST POWER

* SEE 50.2 OF APPENDIX A FOR SUGGESTED PROCEDURE

** IF LOAD IS AN ELECTRICAL MOTOR, OBTAIN DATA BY USING SHEET 2.

LEGEND: NO NON-OPERATIONAL NT NON-TECHNICAL NCT NON-CRITICAL TECHNICAL CT CRITICAL TECHNICAL

PAGE ______ OF ______

FIGURE A-14. Example DoD facility electrical power system load tablulation worksheet.

DoD FACILITY LOAD TABULATION WORKSHEET FOR ELECTRIC MOTORS

ITEM # FROM WORKSHEET 1	NAMEPLATE MOTOR INFORMATION				STARTING LOAD *			CONTINUOUS LOAD (RUNNING/STATIC)					NOTES
	HP	NEMA CODE	ϕ	VOLTS	kVA **	PF	kW **	VOLTS	AMPS	kVA	PF	kW	

LOCKED ROTOR LOAD PER MANUFACTURER OR TABLE A-4

** (LRkVA CAN BE DETERMINED BY USING LOCKED ROTOR AMPERES FOR SINGLE PHASE BY kVA= , $\frac{\text{VOLTS X AMPERES}}{1000}$ OR FOR 3-PHASE BY kVA = $\frac{\text{VOLTS X AMPERES} \times \sqrt{3}}{1000}$)

PAGE____ OF ___

FIGURE A-15. Example facility load tabulation worksheet for electrical motors.

50.2 Sizing procedures. The suggested steps for sizing the facility power load are:

a. Serially number and describe all facility power loads. List in the order most convenient for data collection and use as many sequentially numbered sheets as needed.

b. List power frequency required if other than 60 Hz.

c. Establish power hierarchy designation for the particular load (see 4.2.10 of volume I).

d. Indicate branch feeder number when assigned.

e. Indicate phases required by the load and, when assigned, show phase A, B,C, as appropriate.

f. Enter power consumption of the load in kW in columns 1 through 6, as appropriate. It is important to accurately determine real power consumed. Since inductive loads, such as electric motors, typically represent a low power sheet 2 (DoD facility load tabulation worksheet for electric motors), should be used to determine the kW figure to be entered on sheet 1. The power factor of switch-mode power supplies can also be low. If the manufacturer has not incorporated automatic power factor correction in his design, he must be asked to provide consumption data.

g. Care must be exercised in obtaining total estimated power consumption - this figure will normally be the total of columns 1 and 2. The individual totaling of columns 3 through 6 assists in sizing power conditioning equipment.

h. The determination of engine-generator set(s) size (column 2) is not a simple problem because load shedding, sequencing, simultaneous starts, etc., are all factors. The data obtained, after considering all the factors, may also be used to determine transfer switch size and rating. Final selection of engine-generator set size must also include a factor for future load increases.

60. Useful power conversions and tables. The information in tables A-I through A-VII is intended for use in the facility planning phase to estimate loads, voltage drops, etc. Following equipment selection, the manufacturer should be consulted for exact specifications. The tables concerning sizing of electrical distribution conductors are for quick reference and should be compared with the current version of the National Electric Code (NEC) before a final selection is made.

TABLE A-1. Electrical formulas for determining watts, kilowatts, amperes, kilovolt-amperes, and horsepower.

Torque in lb-ft = $\frac{\text{hp} \times 5{,}250}{\text{rpm}}$ hp = $\frac{\text{Torque} \times \text{rpm}}{5{,}250}$

rpm = $\frac{120 \times \text{frequency}}{\text{no. of poles}}$

Where:
hp = horse ower
rpm = resolutions
p = number of poles

ELECTRICAL FORMULAS

To find	Alternating current three-phase
kVA	$\frac{1.73 \times I \times E}{1000}$
Amperes when horsepower is known	$\frac{\text{hp} \times 746}{1.73 \times E \times \text{Eff} \times \text{PF}}$
Amperes when kilowatts are known	$\frac{\text{kW} \times 1{,}000}{1.73 \times E \times \text{PF}}$
Amperes when kVA is known	$\frac{\text{kVA} \times 1{,}000}{1.73 \times E}$
Kilowatts	$\frac{1.73 \times I \times E \times \text{PF}}{1{,}000}$
Horsepower (output)	$\frac{1.73 \times I \times E \times \text{Eff} \times \text{PF}}{746}$

I = Amperes
E = volts
Eff = Efficiency
hp = horsepower

kVA = Kilovolt-Amperes
kW = Kilowatts
PF = Power factor

TEMPERATURE CONVERSION

Degree C = (Degree F - 32) x 5/9
Degree F = (Degree C x 9/5) + 32

TABLE A-I. Electrical formulas for determining watts, kilowatts, amperes, kilovolt-amperes, and horsepower - continued.

Rules of thumb

At 3600 rpm, a motor develops 1.5 lb-ft per hp.
At 1800 rpm, a motor develops 3 lb-ft per hp.
At 1200 rpm, a motor develops 4.5 lb-ft per hp.
At 550 and 575 volts, a 3-phase motor draws 1 amp per hp.
At 440 and 460 volts, a 3-phase motor draws 1.25 amp per hp.
At 220 and 230 volts, a 3-phase motor draws 2.5 amps per hp.

$$\text{Voltage tolerance \%} = \frac{\text{No load-full load voltage}}{\text{2 x rated voltage}} \text{ X } 100$$

$$\text{Voltage regulation \%} = \frac{\text{No load-full load voltage}}{\text{full load volts}} \text{ X } 100$$

$$\text{Speed regulation \%} = \frac{\text{No load-full load}}{\text{full load speed (rpm)}} \text{ X } 100$$

OHM's LAW: Ohm’s law states that the current in an electric circuit is equal to the pressure (voltage) divided by the resistance. This can be expressed by the equation:

$$\text{amperes} = \frac{\text{volts}}{\text{ohms}}$$

The equations may be written:

DC OHM’S LAW: E = I x R   I = E   R = E

(C OHM’S LAW: E = IZ   I = E $Z = \frac{E}{I}$

Where:

E = volts
F = frequency

I = amperes
R = resistance (ohms)
Z = impedance (ohms)

TABLE A-II. Approximate ampere ratings of ac generators.

POWER FACTOR			SINGLE PHASE		THREE PHASE		
80%		Unity	J20-V	120-/240-V	120-/208-V	120-/240-V	240-/480-V 277-/480-V
kW	kVA	kW=kVA	amp	amp	amp	amp	amp
10.0	12.5	12.5	104	52	35	30	15
12.5	15.6	15.6	130	65	43	38	19
		15.0	125	63	42	36	18
15.0	18.75	18.75	156	78	53	45	23
		17.5	146	73	49	42	21
17.5	21.87	21.87	182		61	53	26
		20.0	167	84	56	48	24
20. 1	25.0	25.0	208	104	70	60	30
25.0	31.25		260	130	87	75	38
				125	83	72	36
30.0	37.5			156	104	90	45
35.5	43.75			182	122	105	53
40.0	50.0			208	139	120	60
45.0	56.25			234	156	135	68
50.0	62.5			260	174	151	75
55.5	68.75			286	191	166	83
60.1	75.0			313	209	181	90
65.0	81.25			339	226	196	98
70.0	87.5			365	244	210	105
75.5	93.75			390	261	226	113
80.0	100.0			417	278	240	120
85.0	106.25			443	295	256	128
90.0	112.5			468	312	271	135
100.0	125.0			520	348	300	150
110.0	137.50			573	382	332	166
115.9	143.75			595	400	346	173
125.0	156.25			651	435	376	188
140.0	175.0			729	486	421	211
150.0	187.5				521	452	226
155.0	193.75				538	468	234
165.0	206.25				575	498	248
170.0	212.5				591	513	256
175.0	218.75				609	527	263
190.0	237.5				660	573	286
200.0	250.0				696	602	300
230	287.5				799	693	346
250	312.5				867	751	376
300	375				1042	903	452
350	437.5				1215	1054	527
400	500				1390	1204	602
450	562.5				1560	1354	676
500	625.0				1734	1500	751

NOTE: Always use kVA ratings when shown or known.

TABLE A-III. Typical running current requirements of motors.

HP	120 V 1-Phase ac		240 V 1-Phase ac		240 V 3-Phase ac		115 Vdc		230 Vdc	
	C	W	C	W	C	W	C	W	C	W
1/6	4.4	14	2.2	14						
1/4	5.8	14	2.9	14			2.9	14		
1/3	7.2	14	3.6	14			3.6	14		
1/2	9.8	14	4.9	14	2.0	14	5.2	14	2.6	14
3/4	13.8	12	6.9	14	2.8	14	7.4	14	3.7	14
1	16.0	12	8.0	14	3.6	14	9.4	14	4.7	14
1-1/2	20.0	10	10.0	14	5.2	14	13.2	12	6.6	14
2	24	10	12.0	14	5.8	14	17.0	10	8.5	14
3	34	6	17.0	10	9.6	14	25.0	8	12.2	12
5	56	4	28.0	8	15.2	12	40.0	6	20.0	10
7-1/2	80	1	40.0	6	22.0	10	58.0	3	29.0	8
10	100	0	50.0	4	28.0	8	76.0	2	38.0	6

C = Full rated current in amperes (amperes while starting are much higher).
W = Minimum wire size permitted by code;
distance for voltage drop.

TABLE A-IV. Locked-rotor current conversion table for motor circuits and controllers.

MAX. HP RATING	Typical motor locked-rotor current (in amperes)					
	SINGLE-PHASE		TWO- OR THREE-PHASE			
	120 V	240 V	120V	208 V	240 V	480 V
1/2	58.8	29.4	24	14	12	6
3/4	82.8	41.4	33.6	19	16.8	8.4
1	96	48	42	24	21	10.8
1-1/2	120	60	60	34	30	15
2	144	72	78	45	39	19.8
3	204	102		62	54	27
5	336	168		103	90	45
7-1/2	480	240		152	132	66
10	600	300		186	162	84
15				276	240	120
20				359	312	156
25				442	384	192
30				538	468	234
40				718	624	312
50				862	750	378

TABLE A-V. Recommended wire size (AWG) for a three-phase motor.

	HORSEPOWER									
VOLTS	1-3	5	7-1/2	10	15	20	25	30	40	50
208	14	10	8	6	4	3	1	0	000	000
240	14	12	10	8	6	4	3	1	0	000
480	14	14	14	12	10	8	6	6	4	3

TABLE A-VI. Characteristics of conductors.

CARRYING CAPACITIES (30 °C 86 °F)						
				In raceway or cable	In free air	
Wire size	Area (Circular mills)	Ohms per 1000 ft. (25 °C or 77 °F)	Bare Copper (Pounds per 1000 ft.)	Rubber covered (Type R)	Rubber covered (Type R)	Weather proof (Type WP)
14	4,109	2.575	12.43	15	20	30
12	6,520	1.619	19.77	20	25	40
10	10,380	1.018	31.43	30	40	55
8	16,510	.641	49.98	40	55	70
6	26,240	.410	79.46	55	80	100
4	41,740	.259	126.4	70	105	130
2	66,360	.162	205.0	95	140	175
1	83,690	.129	258.9	110	165	205
0	105,560	.102	326.0	125	195	235
00	133,080	.0811	411.0	145	225	275
000	167,770	.0642	518.0	165	260	320
0000	211,600	.0509	640.5	195	300	370

TABLE A-VIII. Wire sizes for 120-volt-dc or -ac unity power factor. 2-percent voltage drop (2.4 volts) .

		WIRE SIZE (AWG)						
		14	12	10	8	6	4	2
WATTS (Note 2)	AMPERES AT 120 VOLTS (Note 3)	ALLOWABLE DISTANCE (feet) (Note 1)						
100	.84	550	880	1330	2080	3400	5500	8500
200	1.67	275	440	665	1060	1690	2750	4300
300	2.50	183	290	450	710	1130	1850	2840
400	3.33	137	220	330	530	840	1380	2150
500	4.16	110	175	265	430	680	1100	1700
750	6.25	73	115	177	285	450	740	1140
1000	8.33	55	83	130	214	340	550	850
1500	12.50	36	57	88	146	225	365	575
2000	16.66	27	42	68	104	166	275	430
2500	20.80	22	37	52	83	135	220	365
3000	25.00	18	26	42	68	115	188	285
3500	29.20		23	37	63	94	155	245
4000	33.30		21	31	52	83	134	217
4500	37.50		15	29	46	73	119	176
5000	41.80			26	42	67	108	166
6000	50.00			21	36	57	88	140
7000	58. 30				29	46	78	119
8000	66.60				26	42	67	104
9000	75.00					36	57	93
10000	83.30					31	52	83

NOTES:

1. Fiqures represent a one-way distance in feet for a two-wire run. If a 4-percent voltage drop is permissible, double the distances listed.

2. For other voltages (120, 240, etc.), use the amperes column - disregard the watts column. If only a l-percent voltage drop is allowable, divide the distances listed by 2.

3. For 240-V and 480-V circuits, the information in the table can be used if distances are changed as follows:

TABLE A-VII. Wire sizes for 120-volt-dc or -ac unity power factor, 2-percent voltage drop (2.4 volts) - continued.

a. For single-phase ac circuits:

Using watts - 4 x distance for 240 volts
16 x distance for 480 volts

Using amps - 2 x distance for 240 volts
4 x distance for 480 volts

b. For three-phase ac circuits (assuming a balanced three-phase load):

Using amperes - 4 x distance for 240 volts
8 x distance for 480 volts

Formula for determining wire size under any other condition:

a. Direct current and single-phase systems:

$$CM = \frac{D \times I \times 22}{Ed}$$

b. Three-phase, three-wire systems:

$$CM = \frac{D \times I \times 19}{Ed}$$

Where:

CM = Circular mills - wire size (see table VI)

I = Current in amperes (in the case of three-phase, it is the current in each wire)

D = single distance (one-way length) of the circuit in feet

Ed = Allowable voltage drop in volts (2 percent of 115 volts is 2.3 volts, etc.)

TABLE A–VIII. Units, constants, frequency spectrum, and conversion factors.

A. Conversion factors.

TO CONVERT	TO	MULTIPLY BY	CONVERSELY, MULTIPLY BY
Ampere-hours	Coulombs	3,600	2.778 X 10^{-4}
Atmospheres	millimeters of mercury, 0° C	760	1.32 X 10^{-3}
Atmospheres	inches of mercury, 0° C	29.92	3.34 x 10-^{2}
Atmosphere	pounds of mercury, 0° C	14.7	6.8 x 10-^{2}
Atmosphere	kilopascals	101.3	9.87 x 10^{-3}
Btu (British thermal unit)	Foot-pounds	778.3	1.285 X 10^{-3}
Btu	Joules	1,054.8	9.48 X 10^{-4}
Btu	Kilogram-calories	.252	3.969
Btu	Horsepower-hours	3.929 X 10^{-4}	2,545
Centigrade	Fahrenheit	(C° x 9/5) + 32	(F°- 32) X 5/9.
Centigrade	Kelvin	add 273	subtract 273
Circular mils	Square centimeters	5.067 x 10^{-6}	1.973 x 10^{5}
Circular roils	Square roils	.7854	1.273
Cubic inches	Cubic centimeters	16.39	6.102 X 10^{-2}
Cubic inches	Cubic feet	5.785 x 10-^{4}	1,728
Cubic inches	Cubic meters	1.639 X 10^{-5}	6.102 X 10^{4}
Cubic meters	Cubic feet	35.31	2.832 X 10^{-2}
Cubic meters	Cubic yards	1.308	.7646
Degrees (angular measure)	Radians	.01745	57.2958
Dynes	Pounds	2.248 x 10^{-6}	4.448 x 10^{5}
Ergs	Foot-pounds	7.367 x 10^{-8}	1.356 x 10^{7}
Foot-pounds	Horsepower-hours	5.05 x 10^{-7}	1.98 x 10^{6}
Foot-pounds	Kilogram-meters	.1383	7.233
Foot-pounds	Kilowatt-hours	3.766 x 10-^{7}	2.655 X 10^{6}
Grams	Dynes	980.7	1.02 x 10^{-3}
Grams	Ounces (avoirdupois)	3.527 x 10^{-2}	28.35
Grams per cm	Pounds per inch	5.6 X 10^{-3}	178.6
Grams per cubic cm	Pounds per cu. inch	3.613 X 10^{-2}	27.68

TABLE A-VIII. Units, constants, frequency spectrum, and conversion factors - Continued.

TO CONVERT	TO	MULTIPLY BY	CONVERSELY, MULTIPLY BY
Grams per sq. cm	Pounds per sq. foot	2.0481	.4883
Horsepouer (550 ft.-lb. per sec.)	Foot-lb. per minute	3.3×10^{4}	3.03×10^{-5}
Horsepower (550 ft.-lb. per sec.)	Btu per minute	42.41	2.357×10^{-2}
Horsepower (500 ft.-lb. per sec.)	Kg-calories per minute	10.69	$9.355 \times 10-^{2}$
Horsepower (550 ft.-lb. per sec.)	Kilowatts	0.7457	1.341
Horsepower (Metric) (542.5 ft.-lb. per sec.)	Horsepower (550 ft.-lb. per sec)	.9863	1.014
Joules	Foot-pounds	.7376	1.356
Joules	Ergs	10^{7}	10^{-7}
Kilogram-calories	Kilojoules	4.186	.2339
Kilograms	Pounds (avoirdupois)	2.205	.4536
Kg per sq. meter	Pounds per sq. foot	.2048	4882
Kilowatt-hours	Btu	3,413	2.93×10^{-4}
Kilowatt-hours	Foot-pounds	2.655×10^{6}	3.766×10^{-7}
Kilowatt-hours	Joules	3.6×10^{6}	2.778×10^{-7}
Kilowatt-hours	Kilogram-caiories	860	1.163×10^{-3}
Kilowatt-hours	Kilogram-meters	3.671×10^{5}	2.724×10^{-6}
Liters	Cubic meters	.001	1,000
Liters	Cubic Inches	61.02	1.639×10^{-2}
Liters	Gallons (liq. US)	.2642	3.785
Liters	Pints (liq. US)	2.113	.4732
Poundals	Dynes	1.383×10^{4}	7.233×10^{-5}
Poundals	Pounds (avoirdupois)	3.108 x 10-*	32.17
Radians	Degrees	57.2958	.01745
Sq inches	Circular mils	1.273×10^{6}	$7.85.4 \times 10^{-7}$
Sq inches	Sq centimeters	6.452	.155
Sq feet	Sq meters	9.29 x 10-2	10.76
Sq miles	Sq yards	3.098×10^{6}	3.228×10^{-7}
Sq miles	Sq kilometers	2.59	.3861

TABLE A-VIII. Units, constants, frequency spectrum, and conversion factors - Continued.

TO CONVERT	TO	MULTIPLY BY	CONVERSELY, MULTIPLY BY
Sq millimeters	Circular mils	1.973	5.067×10^{-4}
Tons, short (avoir 2,000 lb.)	Tonnes (1,000 Kg.)	.9072	1.102
Tons, long (avoir 2,240 lb.)	Tonnes (1,000 Kg.)	1.016	.9?342
Tons. long (avoir 2.240 lb.)	Tons, short (avoir 2,000 lb)	1.120	.8929
Watts	Btu per min	5.689×10^{-2}	17.58
Watts	Ergs per sec	10^{7}	10-7
Watts	Ft-lb per minute	44.26	2.26×10^{-2}
Watts	Horsepower (550 ft-lb per sec.)	1.341×10^{-3}	745.7
Watts	Horsepower (metric) (542.5 ft-lb per sec.)	1.36×10^{-3}	735.5
Watts	Kg-calories per min	1.433×10^{-2}	69.77

B. Luminance conversion factors.

1 nit = 1 candela/square meter
1 stilb = 1 candela/square centimeter
1 apostilb (international) = 0.1 millilambert = 1 blondel
1 apostilb (German Hefner) = 0.09 millilambert
1 lambert = 1,000 millilamberts

Multiply number of by To obtain number of ↘	footlambert	candela per sq meter	millilambert	candela/sq in	candela per sq ft	stilb
footlambert	1	0.2919	0.929	452	3.142	2,919
candela/sq m	3.426	1	3.183	1,550	10.76	10,000
millilambert	1.076	0.3142	1	487	1.382	3,142
candela/sq in	0.00221	0-000645	0.00205	1	0.00694	6.45
candela/sq ft	0.3183	0.0929	0.2957	144	1	929
stilb	0.00034	0.0001	0.00032	0.155	0.00108	1

TABLE A-VIII. Units, constants, frequency spectrum, and conversion factors - Continued.

c. Conversion factors for units of length.

Multiply number of by ↘ to obtain number of	Angstroms	Nanometers	Micrometers	Millimeters	Centimeters	Meters	Kilometers	Mils	Inches	Feet	Miles
Angstroms	1	10	10^4	10^7	10^8	10^{10}	10^{13}	2.540×10^5	2.540×10^8	3.048×10^9	1.609×10^{13}
Nanometers	10^{-1}	1	10^3	10^6	10^7	10^9	10^{12}	2.540×10^4	2.540×10^7	3.048×10^8	1.609×10^{12}
Micrometers (Microns)	10^{-4}	10^{-3}	1	10^3	10^4	10^6	10^9	2.540×10	2.540×10^4	3.048×10^5	1.609×10^9
Millimeters	10^{-7}	10^{-6}	10^{-3}	1	10	10^3	10^6	2.540×10^{-2}	2.540×10	3.048×10^2	1.609×10^6
Centimeters	10^{-8}	10^{-7}	10^{-4}	10^{-1}	1	10^2	10^5	2.540×10^{-3}	2.540	3.048×10	1.609×10^5
Meters	10^{-10}	10^{-9}	10^{-6}	10^{-3}	10^{-2}	1	10^3	2.540×10^{-5}	2.540×10^{-2}	3.048×10^{-1}	1.609×10^3
Kilometers	10^{-13}	10^{-12}	10^{-9}	10^{-6}	10^{-5}	10^{-3}	1	2.540×10^{-8}	2.540×10^{-5}	3.048×10^{-4}	1.609
Mils	3.937×10^{-6}	3.937×10^{-5}	3.937×10^{-2}	3.937×10	3.937×10^2	3.937×10^4	3.937×10^7	1	10^3	1.2×10^4	6.336×10^7
Inches	3.937×10^{-9}	3.937×10^{-8}	3.937×10^{-5}	3.937×10^{-2}	3.937×10^{-1}	3.937×10	3.937×10^4	10^{-3}	1	12	6.336×1^{-4}
Feet	3.281×10^{-10}	3.281×10^{-9}	3.281×10^{-6}	3.281×10^{-3}	3.281×10^{-2}	3.281	3.281×10^3	8.333×10^{-5}	8.333×10^{-2}	1	5.280×10^3
Miles	6.214×10^{-14}	6.214×10^{-13}	6.214×10^{-10}	6.214×10^{-7}	6.214×10^{-6}	6.214×10^{-4}	6.214×10^{-1}	1.578×10^{-8}	1.578×10^{-5}	1.894×10^{-4}	1

FIRE PROTECTION

10. Scope. Damage from fires (iind the consequent disruption of operations) can be minimized by the installation of appropriate fire protection systems. The system, or systems (more than one might be necessary), must protect the entire facility and must be of a type appropriate to the facility. The wrong type of system can, like the fire itself, be a threat to the facility. For example, an automatic water sprinkling system can damage electronic equipment, and would be inappropriate for a communications or data processing facility. Often, it is necessary to employ several different types of systems at a given facility. Systems commonly used at DoD facilities include the following:

20. Applicable documents. MIL-HDBK-1OO8, Fire Protection For Facilities Engineering, Design, and Construction.

30. Halon 1301 systems. Halon is a colorless, odorless, nonconductive gas (bromotriflouromethane), which when released in a confined area, extinguishes fires by inhibiting the chemical reaction between fuel and oxygen. It is used in place of CO_2 systems because of the extreme personnel safety hazard created by use of $C0_2$ in confined spaces. There are two types of Halon 1301 systems used at fixed installations: (1) total flooding, and (2) local application. The total flooding system is designed to cover a large area, and would normally be the system used in a computer facility. The local application system focuses on a single point which may be a critical fire hazard such as flammable liquids or other highly combustible materials. Both systems consist of: (1) a pressurized tank with a control valve that may be electrically or manually activated, (2) automatic detection devices, (3) dispersion heads, and (4) an electronic monitor and control panel. Figure B-1 shows a typical Halon 1301 System.

30.1 Design of facilities using Halon systems. Design of the facility is important if a Halon 1301 system is to be used for fire protection. essential that the protected areii be constructed with minimal openings so the tialon, if released, cannot escape from that area. Windows should be of a type that cannot be opened. All doors should have weatherstripping on the top and sides, with an adjustable door sweep at the bottom. Doors should also have automatic closers and signs on both sides stating that the door must remain closed at all times. All air-handling systems, to include heating, cooling, and ventilating systems, should be connected to the electronic control panel in such a way that all systems will shut down at the first indication of a fire alarm. This prevents air from being forced into the room and diluting the Halon, and also prevents the tlalon from being removed from the protected area by return ducts or exhaust fans. Release of Halon may cause an electrostatic charge on ungrounded conductors; therefore, equipment must be grounded in accordance with MIL-HDBK-419. Floor coverings should also be of antistatic material. If an electrostatic charge is allowed to develop, it may reach a potential that could cause a discharge between two objects, which may cause an explosion. Positioning of detectors is also critical. Smoke detectors should be placed away from air conditioning vents which would tend to blow the smoke away from the detector. It is also

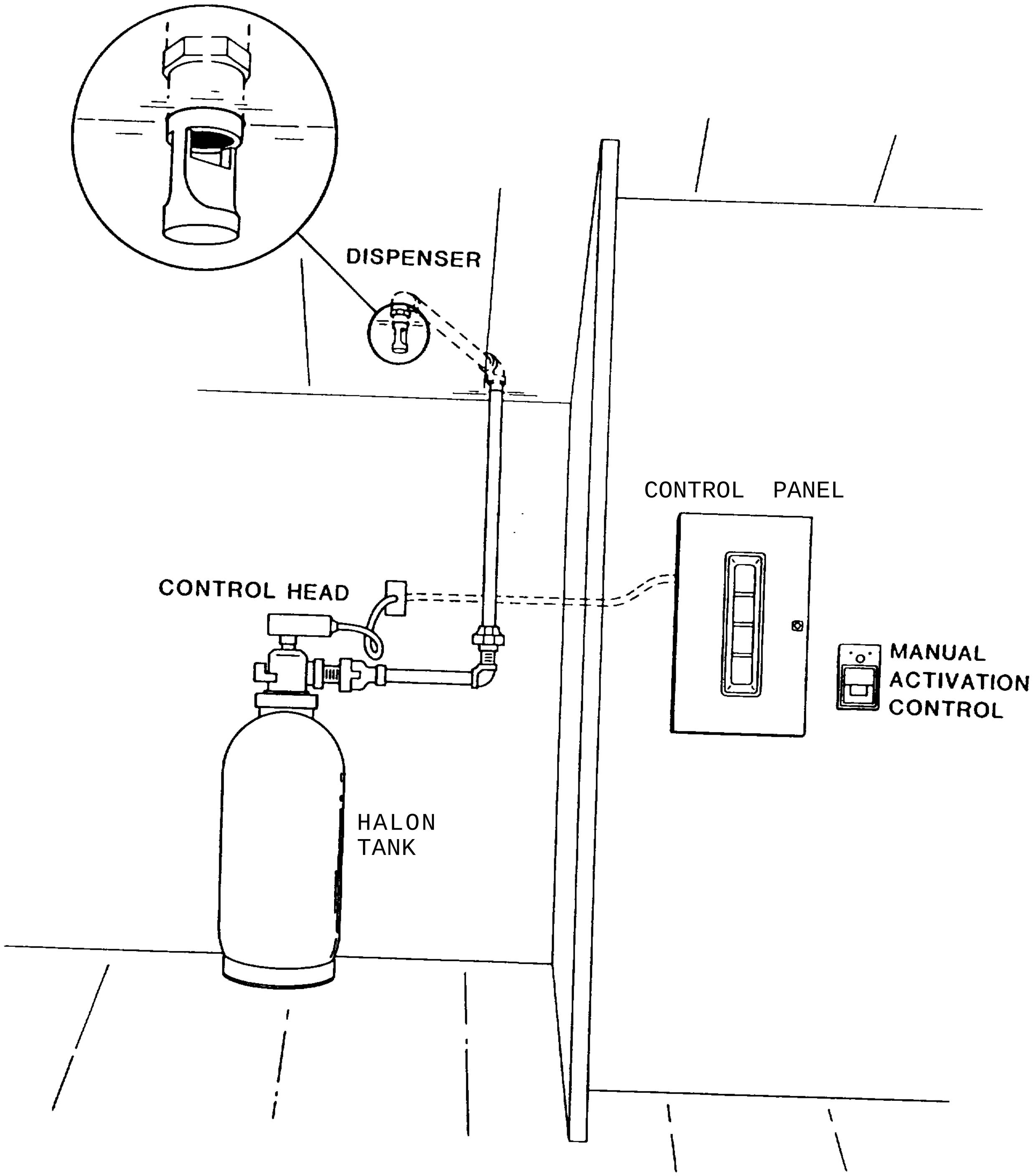


FIGURE B-1. Typical Halon 1301 System.

recommended that a smoke detector be placed near each return air duct and exhaust vent since smoke will naturally be drawn out of the room through these vents. This reduces detection time. Smoke and heat detectors should also be installed above ceilings and under raised floors. Detectors under raised floors should be positioned as shown in figure B-2.

30.2 Exposure of personnel to Halon. Exposure to Halon should be avoided whenever possible. There is not serious risk to personnel from exposure to Halon 1301 vapors for brief periods, but exposure for extended periods or to high concentrations may cause dizziness, impaired coordination, and irregular cardiac rhythm. Usually these symptoms disappear when the individual leaves the area, but continued exposure may be fatal-. It has also been reported that Halon may cause damage to the earth’s ozone layer.

40. Automatic water sprinkling systems. NFPA 13 requires automatic water sprinkling systems to be installed in areas where highly combustible materials are used or stored, or have been used in construction of a building. Other areas should be evaluated to determine if it is practical to install such systems. When designing automatic water sprinkling systems, the following factors must be considered:

a. What is the possibility of fire in the area?

b. What combustible material is used or stored in the area, or was used in construction of the building?

c. Is the area protected by other systems such as a Halon 1301 or an early warning system?

d. Is the equipment density in the area high or low?

e. Will unacceptable damage be caused if the water system is activated, either by a fire or accidentally?

If the likelihood of fire is low and equipment or material is susceptible to water damage, sprinkler systems should be avoided, and a Halon 1301 or an early warning system installed. It may be advisable to avoid sprinkler systems in areas where water pressure is low.

40.1 Types. There are four types of automatic water sprinkling systems: (1) wet-pipe, (2) dry-pipe, (3) pre-action, and (4) deluge. Met-pipe systems employ automatic sprinklers attached to pipes connected to a water supply. The pipes are filled and the sprinklers discharge water immediately when opened by heat of a fire. The dry-pipe system contains pressurized air or nitrogen. When the sprinklers are opened, as by heat of a fire, the gas pressure drops water pressure from the supply to open a valve, and water flows into the pipes to be dispensed from the sprinklers. The pre-action system employs automatic sprinklers connected to pipes containing air that may or may not be under pressure. A supplemental fire detection system is installed in the same area as the sprinkling system. When the detection system is activated, a valve opens,- permitting-water to flow into the pipes and to be discharged through the sprinklers (which have been opened by the fire). The deluge system is similar to the pre-action system, but uses open sprinklers instead of closed ones.

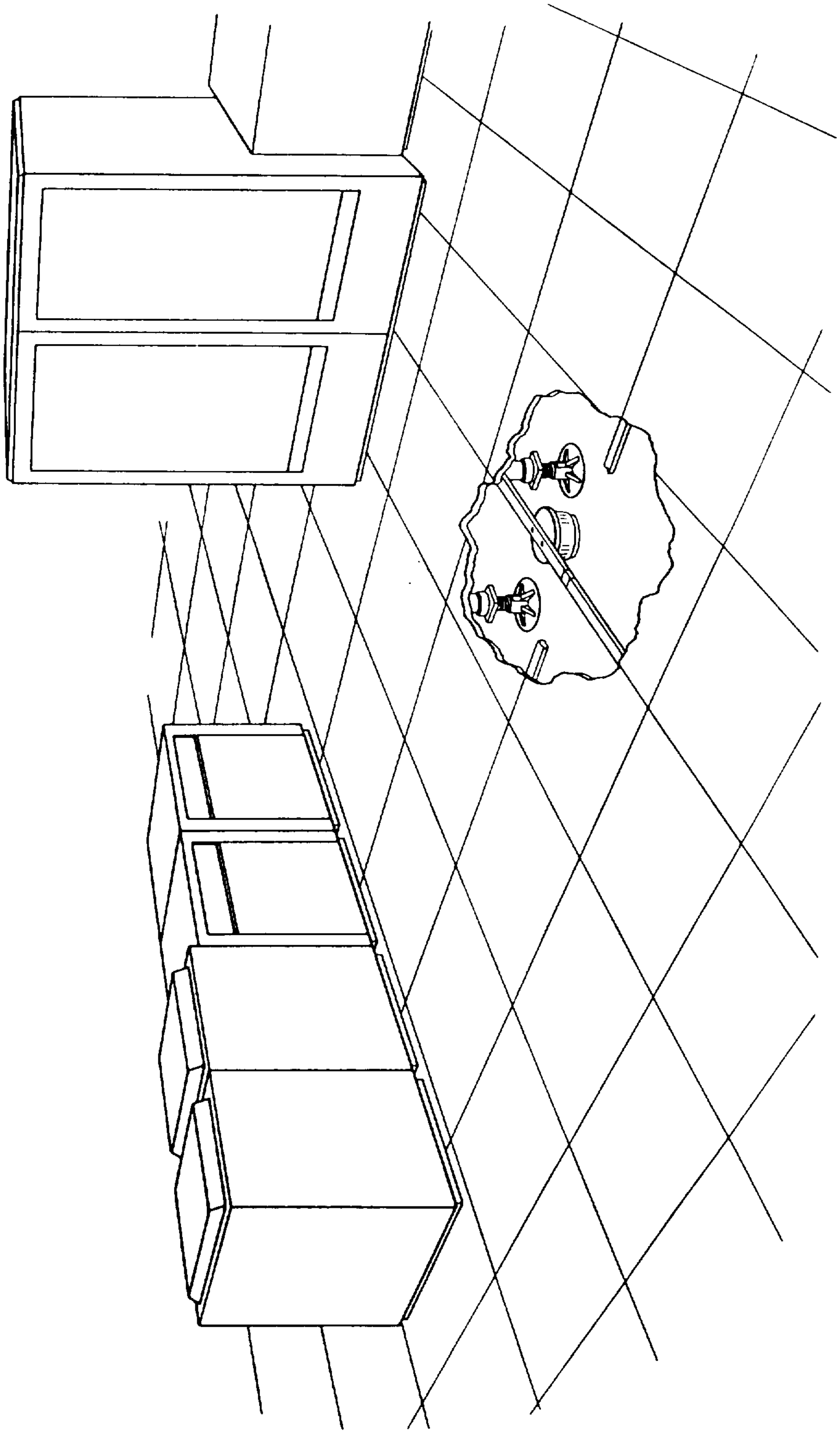


FIGURE B-2. Under-floor detector mounting.

40.2 Installation. When installing an automatic water sprinkling system, it is important to place the sprinklers so they will provide total, overlapping coverage. of the protection area. If high objects block coverage of certain spaces within the protection area, additional sprinklers should be installed to provide total coverage. Because they are controlled and activated electronically, pre-action and deluge systems are preferable to other types of sprinkler systems. An electronic control panel should be installed in the protection area. This panel should be connected to the central control panel or monitor station, and should be equipped with an abort function so that water dumping could be prevented if the system should be accidentally activated. If a wet-pipe or dry-pipe system is used, there is little chance of stopping water dumping in the event of accidental activation.

50. Early Warning System. The early warning system is designed to provide fire protection in areas where use of an automatic water sprinkling system may damage a facility, and use of a Halon 1301 system is not warranted due to low equipment density. An early warning system consists of heat and smoke detectors, local audible and visual alarms, an electronic monitor and control panel, and a reliable means of communication. The heat and smoke detectors are designed to detect the earliest signs of smoke or unusual temperature rise. When the system is activated, the local alarms are energized, and a signal is automatically transmitted to a monitor station.

For this type of system to be effective: (1) the communication link between the facility and the monitor station must be highly reliable. The desired reliability is 95 percent. Since this may not be attainable in some areas, the reliability should not be below 80 percent, and (2) the response time of the fire department after notification should be 5 minutes or less. If the response is more than 5 minutes, other protective systems should be considered.

The communication link may be a dedicated line through the local telephone exchange, an automatically dialed high-priority telephone circuit, or a radio link. When using either type circuit through the telephone exchange, 24 Vdc must be provided. This may be supplied by the facility central control panel or by the telephone exchange. When the system is activated, the polarity of the dc is reversed, triggering an alarm at the monitor station. The monitor station then notifies the support fire department.

When designing an early warning system, the first step is to determine the reliability of the communication link. Telephone circuit, or a radio last six months should be reviewed to determine the number and cause of outages, average downtime, and corrective action taken. If the period of time reviewed does not cover the period of peak thunderstorm activity in the area, the latter period should also be reviewed. If acceptable reliability cannot be achieved, an early warning should not be used. If a radio is to be used, it is important to determine If any equipment in the facility can interfere with and reduce the reliability of the radio link. It is also important to survey adjacent facilities and the line-of-sight path between the facility and the monitor station to identify other sources of potential interference (e.g., radio or television broadcast stations). Since the early warning system is usually used without a fixed fire extinguishing system, it is recommended that portable fire extinguishers be strategically placed throughout the facility.

60. Detectors. The selection, positioning, and installation of detectors depends on facility design, equipment configuration, type of”equipment, materials in the construction of the building used, and the anticipated fire potential. Usually a combination of heat, smoke, and flame detectors works better than one type of detector used alone. Typical detectors are shown in figures B-3a through B-3d.

60.1 Heat detectors. Heat detectors have the lowest false alarm rate, but are also the slowest in detecting fires. They are designed to activate a fire alarm when the temperature of their elements exceeds a fixed temperature rating (usually 135 °F (57 °C) or 200 °F (93 °C)). There are three common types of heat detectors: (1) eutectic (fusible) metal, (2) glass bulb, and (3) bimetal. The eutectic type uses alloys of bismuth, cadmium, lead, or tin for elements. These elements are designed to melt at the rated temperature, thus activating the alarm. This type is not restorable, and therefore must be replaced after it has been activated. The glass bulb detector is the least commonly used type. It consists of a switch which is normally open, a built filled with liquid under high pressure with a small bubble. When heated, the liquid expands and compresses the air bubble. When the air bubble has been totally absorbed, a rapid increase in pressure occurs and the bulb breaks, closing the switch and activating the alarm. There are two types of bimetal detectors: (1) bimetal strip, and (2) the bimetal disc. Both types employ a switch consisting of two metals with different thermal expansion coefficients. When the metals are heated, the metal stri or disc with the higher expansion coefficient bends toward the one having tRe lower expansion coefficient. When the two pieces of metal contact each other, the alarm is activated. When the source of heat has been eliminated, the metals cool and separate, thus restoring the detector to normal monitoring condition. The strip detector, although effective, has a relatively slow response time. The disc type has a rapid response time and is more effective for early fire detection. A major disadvantage of bimetal detectors is that they often cause false alarms due to vibration. This is especially true as the room temperature approaches the threshold temperature of the detector.

60.2 Smoke detectors. There are two common types of smoke detectors: photoelectric detectors, and (2) ionization detectors. Photoelectric detectors operate by sensing a change in the intensity of light received by a photo receptor. When smoke is present, light is reflected onto the light-sensitive photocell, causing its resistance to decrease. This causes an increase in current which is electronically amplified to produce an alarm voltage. The advantages of photoelectric detectors are: (1) fast response to smoldering fires, (2) fast response to smoke regardless of the distance smoke has travel led, (3) fast response to overheated pvc wire insulation, (4) insensitivity to air velocity, and (5) the ability to install in areas where control led fires are present or where nonflammable gases or vapors are normally found. Some disadvantages are slow response to: (1) fast-flaming fires, and (2) combustion particles having a diameter smaller than the wavelength of the light source.

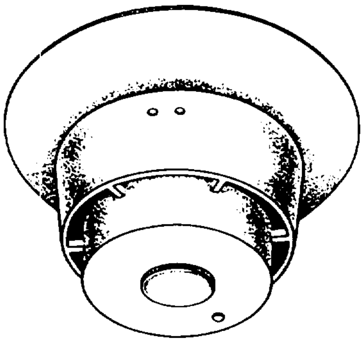


FIGURE B-1A PHOTOELECTRIC SMOKE DETECTOR

FIGURE B-3a. Photoelectric smoke detector.

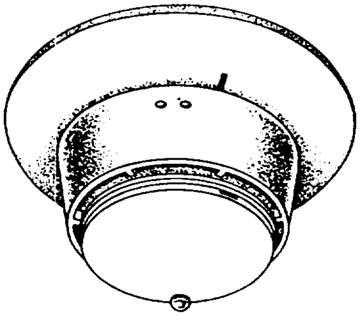


FIGURE B-1B IONIZATION SMOKE DETECTOR.

FIGURE B-3b. Ionization smoke detector.

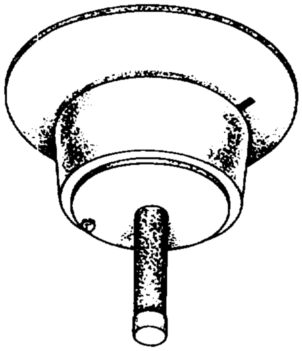


FIGURE B-1C HEAT DETECTOR

FIGURE B-3c. Heat detector

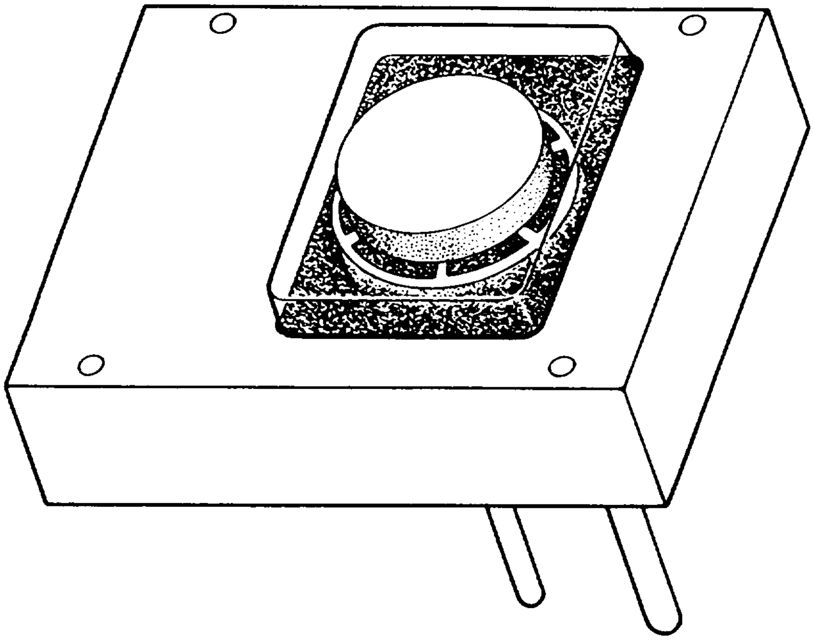


FIGURE B-3d. Duct detector.

60.3 Ionization detectors. Ionization detectors operate by sensing a change in the electrical properties of a chamber containing minute quantities of radioactive material. Alpha emissions from this material ionize the air between two plates. When combustion products from a fire enter the chamber, they change the impedance of the chamber, causing a voltage shift and triggering an alarm. The advantages of ionization detectors are: (1) quick response to fast-flaming fires, (2) quick response to fires that produce only a small amount of smoke and no visible flame, and (3) sensitivity to a wide range of combustion products. The disadvantages are: (1) slow response time to smoldering fires, (2) changes in sensitivity due to altitude or the presence of radiation sources in the environment, and (3) changes in sensitivity due to sudden changes in temperature, humidity, and barometric pressure. Many ionization detectors, however, employ designs to compensate for the effects of temperature, humidity, air pressure, altitude, etc.

60.4 Flame detectors. Flame detectors sense ultraviolet or infrared radiation produced by flames or glowing embers. Flame detectors have the fastest response time of all types of detectors, but, unfortunately also have a high false-alarm rate. Areas in which this type of detector is employed should be designated as nonsmoking. Care must be taken to ensure that no objects are positioned so that they can block the “vision” of the device. This type detector should be used only in areas of extremely high risk, such as fuel storage areas, and should not be used in operations or equipment areas.

60.5 Duct detectors. Duct detectors are typically smoke detectors which are installed inside air conditioning ducts. They should be placed close to possible sources of fire, such as fan motors or compressors.

70. Fire prevention. The most effective method of fire protection is prevention. All construction materials should be flame retardant. In addition, wall, floor, or roof penetrations should be equipped with a fire-stop barrier to prevent flame or smoke from passing from one area to another. Foamed silicone elastomer is used to provide such a barrier, since it is fire resistant, stable at high temperatures, and easily installed. foam is sprayed around the penetrations to provide a complete, air-tight seal. Since it is a two-part mixture, the silicone expands when the two parts are mixed, closing around the penetration. Additional treatment may be provided by spraying the foam inside floors, walls, and ceilings.

PHYSICAL SECURITY

10. Scope. The need for providing physical security depends on the geographical location and vulnerability of the facility and the criticality of this mission. Physical security measures may include access control, perimeter fences, perimeter lighting, closed circuit televison (CCTV), and an intrusion detection system. This appendix provides general physical security guidelines.

20. Applicable documents. MIL-HDBK-1013/l , Design Guidelines for Physical Security of Fixed Land-Based Facilities.

30. Access control. There are numerous methods of providing access control. Among these methods are guard force, mechanical or electronic cipher locks, dial combination locks, key locks, and internally controlled electrical door releases. Recent developments in biometric access control can be used for access when permitted by individual service publications. Biometric access control is the method of identification and verification in which the person seeking access is identified by fingerprints, palm pattern and geometry, retinal pattern, voice analysis, signature dynamics, and other methods.

30.1 Guard force. A guard force may be employed to provide access control. This method is quite effective, requiring some form of personal recognition or identification. Usually, access rosters are provided to guard personnel, listing all personnel who are authorized access to the facility. The guard is responsible to positively identify individuals and verify authorization. Since comparing identification by checking the access roster would be too time consuming in large facilities, a pass or badge system may be effective. Passes or badges should include a photograph of the individual to whom they are issued. They must be closely controlled and should be withdrawn when access is no longer authorized. Visitors to the facility should be issued a temporary badge or pass after formal identification has been provided, and the need for access established. Infrequent visitors should be accompanied by an escort (usually a person assigned to the facility) while in the facility. An access roster may be provided to guard personnel for frequent visitors to the facility. These personnel may be granted access as authorized by the local security manager.

30.2 Mechanical or electronic cipher locks. Cipher locks are combination locks which are opened by pushing a series of buttons or switches. A cipher lock may be used for access control during normal working hours or when the facility is manned. They should never be used to provide physical security for unmanned or part-time facilities. It should be noted that electronic cipher locks should be equipped with backup battery power to permit access during power outages.

30.3 Dial combination locks. This type lock is generally used on doors inside the facility and not on outside entrances. Group I dial combination locks provide a high degree of physical security and may be used when the facility is unmanned. This type lock is frequently used with a cipher lock. During the time that a facility is manned, the dial lock may remain open. Access would be controlled by the cipher lock.

30.4 Internally controlled electric door release. This type of access control may be used internally if access to the entire facility is controlled. Access authorization must be verified when using this method. This may be done by using a guard inside an entrance to the controlled area to properly identify personnel.

40. Perimeter fencing. Perimeter fences may provide a high degree of access control. The distance from the facility that a fence is installed is dependent on the available real estate and the need for facility protection. The distance should be great enough to permit detection, prior to reaching the facilities, of personnel who have successfully penetrated the perimeter barrier. Chainlink fences are recommended and may be extended by installing three strands of barbed wire atop the fence. Fences should be a minimum of 8 feet high without barbed wire. All fence posts should be securely anchored in concrete to prevent removal or the fence being easily pushed over. gates should be equipped with locking mechanisms and remain secured when not in use. Personnel access gates may be equipped with cipher locks but should have other locking mechanisms such as padlocks for periods of time when the facility is unmanned.

50. Perimeter lighting. The major function of perimeter lighting is to provide visibility of the area surrounding the facility during hours of darkness. When properly installed, lights may also be effective as a deterrent to attempted barrier penetration. It is important when designing a perimeter lighting system to use lights with rapid turn-on time and recovery time after power outages.

50.1 Types of perimeter lights. Among the types which may be used are incandescent, mercury vapor, fluorescent, tungsten-halogen, metal halide, high pressure sodium, and low pressure sodium.

TABLE C-1. Comparison of perimeter lighting types.

Lamp type	Lamp efficacy (Lumens per Watt)	Life (hours)
Incandescent	9-22	750-2,500
Fluorescent	45-95	7,500-20,000
Metal halide	80-115	7,500-15,000
High-pressure sodium	80-140	12,000-24,000

50.2 Installation practices. Exterior perimeter lighting may be installed by using direct or indirect illumination. Lights should be installed on or near the roof of the structure and should be positioned to provide total coverage of the areas surrounding the facility. If the lights are not adequate for providing light beyond the perimeter fence, if installed, lights should be installed on poles at the fence line to provide illumination for an adequate distance beyond the perimeter barrier. A safe distance may be defined as a minimum of 15 feet, but may be greater, depending on the terrain and threat of penetration. Indirect lighting involves installing lights away from the structure, pointing toward it. This will provide backlighting to easily detect intruders. If it is necessary to provide lighting beyond the perimeter, lights may be installed facing both directions, providing lighting from the perimeter to the facility and external to the perimeter barrier.

60. Closed circuit television (CCTV). This type system may be used for physical security inside and outside the facility. This system is particularly effective for monitoring hallways, doors, and perimeters. The CCTV system consists of a monitor station and cameras installed in strategic locations.

60.1 Monitor station. The monitor station should be located in an area within the facility which is out of the main personnel areas and provides adequate accessibility to the area protected by the system. Monitor stations may be configured with one monitor with a mechanism to select one camera at a time for viewing, or they may have a monitor for each camera. In high security facilities, the latter configuration is more effective.

60.2 Cameras. Cameras should be positioned to provide maximum coverage of the area to be monitored. When used to monitor open areas or as perimeter monitors, cameras should be spaced in such a way that the field of view overlaps that of adjacent areas to ensure complete coverage. Cameras should also be installed in a position where tampering is difficult. Additional protection should be provided by installing all power and signal cables for the system in conduit or duct. When cameras are used to monitor exterior perimeters or dimly lighted areas, additional lighting as specified by the manufacturer may be needed.

70. Intrusion detection system (IDS). An intrusion detection system may be used in facilities to provide additional protection. IDSs typically consist of magnetic switches and motion sensors. All exterior entrances, open areas, and sensitive areas within the facility should be protected. Motion sensors may be installed to provide general coverage of open areas to prevent an intruder from crawling under the area of coverage. Areas protected that require only periodic access should be armed at all times except when authorized access is necessary. The IDS should connect to a remoted monitor station through a dedicated line or autodial telephone line.
in providing notification to the appropriate police or security agency. The IUS should be designed as specified in appropriate security documents.

APPENDIX D
CHECKLISTS

10. Scope. This appendix provides checklists for site survey engineering, power-system evaluation, and energy conservation.

20. Applicable documents. This section is not applicable to this appendix.

30. Site survey engineering checklist.

Date: ______________

Name of Facility: ____________________________ Location: ______________________

Person(s) completing checklist: ____

____

Identification

1. Has the facility been completely and accurately identified?

Latitude: ________________ Longitude: ________________ Elevation: ______________

Map Sheet Number: ____

Map Coordinates: ______________________ Nearest City/Town: _____________________

County/State/Country: ____

Weather

2. Has meteorological data for the site location been thoroughly researched? Use of triservice Engineering Weather Data Manual (TM 5-785, NAUFAC P-89, AFM 88-29) is mandatory within DoD.

a. Design temperatures.

(1) Summer dry bulb and wet bulb: ______________________________________

____

(2) Winter dry bulb and wet bulb: ______________________________________

____

b. Humidity conditions.

(1) Relative humidity (typical , by month): _______________________________

____

c. Degree days.

(1) Heating: ______________________________

(2) Cooling: ______________________________

d. Precipitation.

(1) Rainfall (by month): ______________________________

____

(2) Snowfall (by month): ______________________________

____

(3) Ice formation (by month): ______________________________

____

(4) Damaging hail potential (by month): ______________________________

____

e. Prevailing winds.

(1) Direction (by month): ______________________________

(2) Speed (by month): ______________________________

f. Solar radiation.

(1) Solar angle (by month): ______________________________

(2) Average daily hours of sunshine (by month): ______________________________

____

(3) Average intensity (Btu/hr x ft^2 or W/m^2) (by month): ____________

____

Lighting.

(1) Density (by month): ______________________________

(2) Unusual weather potential (monsoon, tornado, hurricane, sand storm) month): ______________________________

Geographical features.

Have important local geographical features which could affect building siting and design been identified and analyzed?

a. Hills and mountains (as they affect weather, winds, and solar radiation):

b. Bodies of water (as they affect

provide potable source, serve as heat

c. Vegetation (as it provides soil erosion protection, wind screening, blocking of solar radiation):

d. Seismic activity:

e. Vulnerability (as created by proximity to target areas, dangerous activities, hazardous materials, or other risks):

f. Soil conditions: Has local soil been tested for construction, chemical, and electrical properties?

On-site support.

a. Have on-site support capabilities been determined?

a. Power capability and reliability: see volume II,

checklist:____

b. Other utilities.

(1) Water supply (quality and quantity): ____________________

(2) Sewage disposal:____________________________________

(3) Centralized heating/cooling plant:______________________

(4) Natural gas:_______________________________________

c. Maintenance.

(1) Mission (other information systems activities which have repair and testing facilities):____

(2) Support (other DoD activities which have maintenance capabilities):

d. Communications.

(1) Voice (access to military and civilian networks): ____________________

____

____

(2) Data (access to military and civilian networks): ____________________

____

e. Transportation.

(1) Air: ____

(2) Ground: ____

(3) Sea: ____

f. Supply.

(1) Parts/materials: ____

____

(2) Storage: ____

g. Housing.

(1) Dormitory: ____

(2) Family: ____

(3) Transient: ____

h. Food service.

(1) Types (dining halls, cafeterias, fast food, etc.): ___________________

(2) Capacities: ____

(3) Operating hours (24 hrs for shift workers): __________________________

____

i. Administration:

____

j. Personnel services:

____

k. Medical and dental: ____

(1) Hospital (no. of beds, types of clinics, dependent care): __________

____

____

(2) Clinic (no. of beds, types of services, dependent care): __________

____

5. Off-site support.

a. Power sources (capacity/reliability):

____

b. Other utilities.

(1) Water supply (quality and quantity): ________________________

____

(2) Sewage disposal: ____

(3) Natural gas: ____

c. Maintenance and services.

(1) Communications repair and parts: __________________________

____

(2) Data processing repair and parts: __________________________

____

(3) Other types of repair and parts: __________________________

____

d. Communications.

(1) voice (access to networks): ______________________________

____

(2) Data (access to networks): ______________________________

____

e. Labor sources.

(1) Construction ______________________________
(2) Other skilled: ______________________________

(3) Manual : ______________________________

f. Transportation.

(1) Access roads (condition and capacity): ______________________________

____

(2) Air (proximity of airport): ______________________________

____

(3) Ground (road and rail): ______________________________

____

(4) Sea (proximity of port facility): ______________________________

____

g. Energy and fuel sources.

(1) Coal: ______________________________

(2) Oil : ______________________________

(3) Natural gas: ______________________________

(4) Geothermal : ______________________________

(5) Solar: ______________________________

h. Housing.

(1) Houses: ____________________

(2) Apartments: ____________________

i. Food service.

(1) Restaurants (type and hours of operation): ____________________

____

(2) Fast foods (type and hours of operation): ____________________

____

j. Recreational facilities:

____

____

k. Local standards, laws, and customs (as they influence the operation of a DoD facility).

(1) Construction practices and standards: ____________________

____

(2) Social customs: ____________________

____

(3) Geopolitical considerations: ____________________

____

(4) other considerations: ____________________

____

40. Power system checklist.

1. Name, address, and telephone number of power supplier: ____________________

____

2. Location of power generating plant: ______________________________

____

3. Location of nearest substation: ______________________________

____

4. Available power: Voltage ____________________ Frequency: ____________________

5. Method of power distribution: Overhead Underground

6. Is available power adequate? Yes No

7. Will a dedicated transformer(s) be required? Yes No

8. Will transient voltage protection be incorporated into the power company switch gear at the facility entrance? Yes No

9. If transient suppressors are to be installed, will they be between the power transformer and switch gear? Yes No

10. Is backup power required? Yes No

11. If backup power is required, what types of systems will be used?

____

____

12. Will frequency conversion be required to power fixed or mobile DoD equipment? Yes No

13. Have tests been conducted to determine soil resistivity and conductivity? Yes No

14. What facility grounding method will be used? ____________________

____

15. Will air terminals (lightning rods) be used for lightning protection? Yes No

16. Will dedicated power panels and isolated ground outlets be used for sensitive electronic equipment? Yes No

17. Will facility transient suppressors be installed? Yes No

18. What type of suppression devices will be used? ____________________

____

19. Where will the suppression devices be installed? ____________________

____

20. Will facility powerline filters be required? Yes No

21. Are transient protectors built into equipment which will be operated in the facility? Yes No

22. Will equipment be used in the facility that may generate transients which could affect other equipment? Yes No

23. Will isolation transformers be used in areas where sensitive electronic equipment is installed? Yes No

24. Are other power subscribers nearby which may generate powerline transients? Yes No

25. What is planned to reduce or eliminate the effect of these transients?

____

____

26. Is the facility in an area of high lightning activity? Yes No

27. What is the frequency of electrical storms in the area? ____________________

____

28. Will equipment be installed which requires dc voltage? Yes No

29. What dc voltages are required? ____________________

____

30. What method will be used to supply dc voltages?

a. Rectifier/chargers and batteries b. Rectifiers
c. Dc generators d. Converters

31. Will dc-to-dc converters be used? Yes No

32. Will emergency backup power be required? Yes No

33. What type of emergency conversion will be used?

a. Static UPS b. Rotary UPS Battery c. Alternative power source

34. If a battery room is usea, have adequate safety measures been considered? Yes No

35. Will only mission essential equipment be used while power is being supplied by backup systems? Yes No

36. How long must operation be sustained when power is being supplied by backup systems?______________________________

37. Will the backup power system provide for sustained operations as required? Yes No

50. Energy conservation checklist for environmental control.

1. General information.

a. Do site survey data include complete information on local weather conditions?

b. Do site survey data include useful information concerning site features which can affect energy consumption?

c. Have the appropriate design conditions been used to determine the types and sizes of environmental control equipment?

d. Will environmentally sensitive electronic areas, such as computer rooms, be provided with dedicated and backup HVAC systems?

e. Has an energy management program been established for the facility?

2. Heating system.

a. Have all heating requirements been included in heating load calculations?

b. Has use of an economical and available fuel source been considered in the selection of heating equipment?

c. Have fuel efficiency, heat recovery applications, and other energy-saviny techniques been considered in the design of the heating system?

d. Will forced-air ductwork or hot water piping be properly insulated?

e. Will forced-air ductwork and hot water piping be provided with the necessary dampers and valves, respectively, to balance and control flow rates?

f. Has a reasonable growth potential been incorporated into the heating system design?

3. Cooling system.

a. Have all cooling requirements been included in cooling load calculations?

b. Where acceptable, has energy-efficient cooling equipment been selected?

c. Has the cooling equipment been matched to the characteristics of the total cooling load (sensible cooling versus latent cooling)?

d. Have energy-efficient techniques such as economizer cycles, off-peak operating cycles, and VAV systems been considered in the design?____________

e. Has a reasonable growth potential been incorporated into the cooling system design?____________

4. Solar energy.

a. Does the architectural design of the facility consider the control and application of solar radiation?____________

b. Will solar energy be applied for building heating and cooling?____________

c. Has daylighting been considered in building design?____________

d. Will solar energy be used to produce hot water?____________

5. Construction.

a. Will the construction materials and techniques used produce a tight building, which minimizes unwanted heat gains and losses?____________

b. Will the building be properly insulated, to reduce heating and cooling loads. ____

____

c. If building is hardened, will the potential environmental control advantages be exploited? ____

____

d. Will sensitive electronic areas, such as computer rooms, be configured and operated so that the indoor environmental conditions can be maintained without excessive operation of HVAC equipment? ______________________________

____

____

DESIGN CONCEPT FOR AN EFFICIENT SMALL FACILITY

10. Scope. This appendix shows an earth-sheltered design concept that could be applied to small DoD electronics facilities in all but artic locations. It is a facility that can be operated unattended or attended. Although glass is used extensively for heating, cooling and daylighting, the structure is relatively invulnerable to functional damage by weather, vandalism, or terrorism.

20. Applicable documents. This section is not applicable to this appendix.

30. Definitions. See section 3.1 of this handbook.

40. Design features.

40.1 Site selection. An earth-sheltered building, such as depicted in figure E-1, can be built on any terrain. Although preferred, it is not necessary to use a south-sloping (Northern hemisphere) hill for an earth-sheltered building. It can be constructed on level ground and the physical and economic benefits obtained by earth berming. With either type of site, a swale is required behind the structure to obtain necessary drainage. Core samples should be taken at any prospective site to determine exact soil conditions.

40.2 Advantages. The advantages of an earth-sheltered building are:

a. Physical security - weather, fires, and vandals are not likely to damage a building of poured concrete with earth *cover* on three sides and the top. The lower profile and basic construction methods afford some blast resistance. Nuclear radiation effects can easily be reduced by a factor of 50 to 1000.

b. Less problems with EMI and noise - the effects of EMI from external sources is reduced by the surrounding earth; a facility ring ground can be easily located at a depth where the soil will remain moist and highly conductive. Audible noise control at facilities near runways or highways is vastly improved with earth-sheltered construction.

c. Lower cost heating and cooling - several feet of earth cover make it possible to heat and cool the facility for a small fraction of the cost for an above-ground structure. Exterior maintenance costs are greatly reduced as well as the chance of structural damage due to wind.

40.3 Theory of operation - winter. The addition of a Trombe wall a few inches behind the south-facing windows vastly improves security and offers a method to furnish most of the required heating. Trombe walls are usually 6 or more inches thick and made of poured concrete. Small slots (vents) with specific dimensions are used to control the heating cycle as shown in figures E-2a and b. As expected, if the glazing is damaged from any cause,

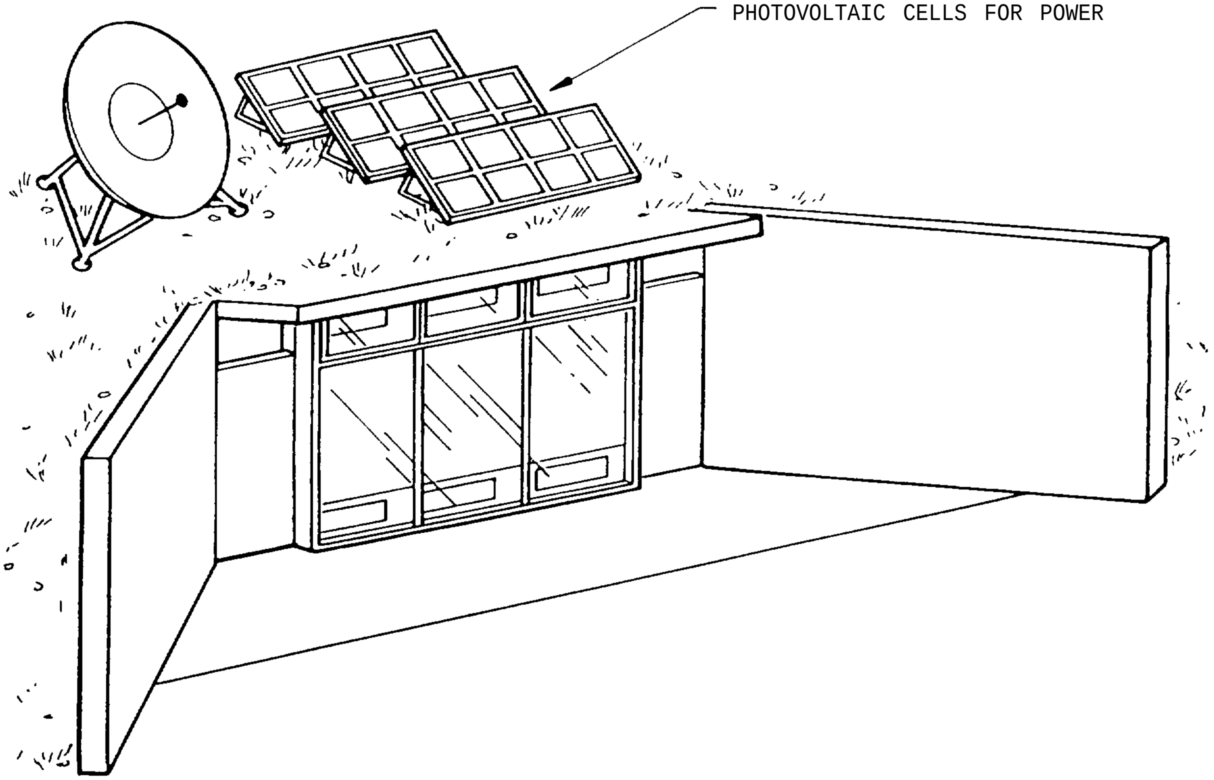


FIGURE E-1. Earth-sheltered building.

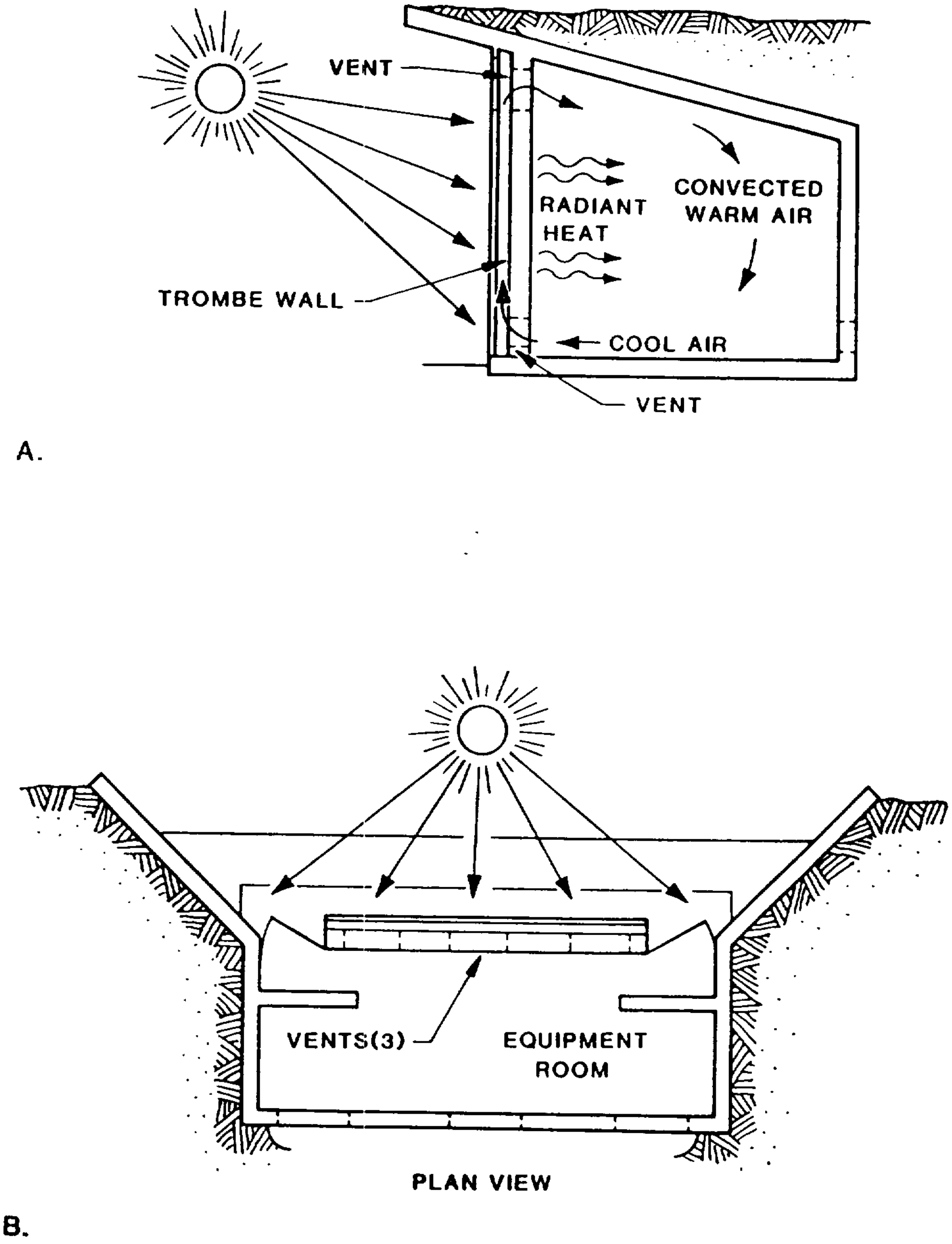
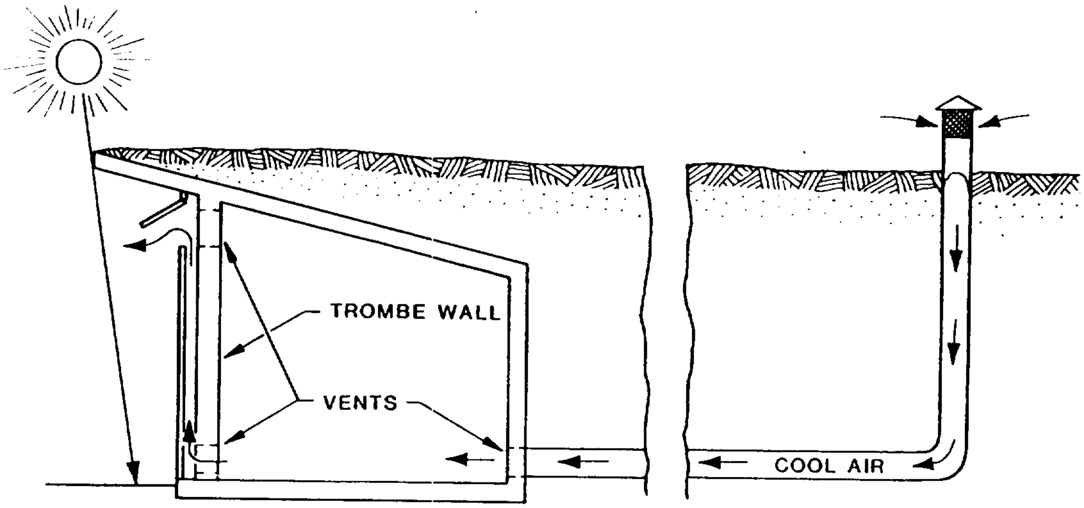


FIGURE E-2. Winter operation.

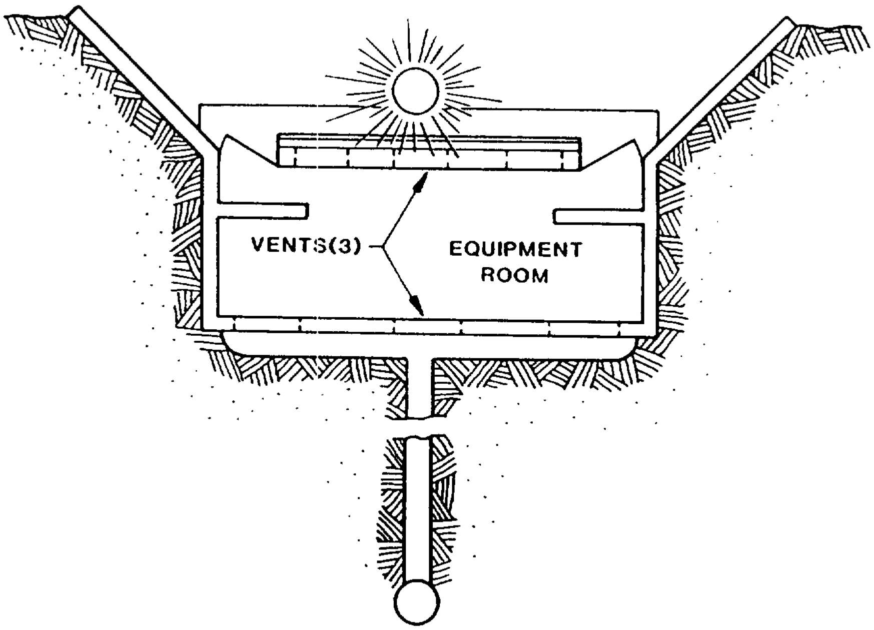
some of the natural heating will be temporarily disrupted, but access to the building by unauthorized personnel continues to be denied. The small slots in the Trombe wall can also be covered with expanded metal to prevent access to the interior by tossed objects. Heating with a Trombe wall is classed as indirect gain, where solar energy is absorbed on the outer surface of a masonry wall, but transfer through the wall is delayed. Properly designed, the outer surface of a glazed concrete wall gets very hot during the day and the heat penetrates the wall and warms the inside of the structure after sunset. This arrangement also pulls cooler air from the floor (figure E-2a and b) through the lower vents and across the hot surface between the glass and concrete. This rising column of air is heated by thermosiphon action and returned to the room. At night, the lower vents automatically close to prevent loss of building heat.

40.4 Theory of operation - summer. In sumner, the Trombe wall is used to provide cooling (figure E-3), a and b). The structure roof overhang is carefully sized (based on latitude) to reduce the amount of solar radiation impacting the outer surface of the wall during the summer months. The upper Trombe wall vents are opened to the outside, and rear floor level vents are opened to accept air from a cool tube. Cool tubes have typical dimensions of d inches (20 cm) in diameter and 100 feet (30 m) in length, and are buried at the constant-temperature level of the particular geographic location. The warm, front surface of the Trombe wall pulls the cool air from the floor and exhausts it between the glass and the wall, and outside through the open top vents. The usual application of media filters will be required to control dust and other particulate. In high humidity areas, it may be necessary to provide a dry sump at the bottom of the vertical portion of the cool tube.

40.5 Limitations on using natural heating and cooling. As expected, equipment that requires precise control of humidity and temperature is not a good candidate for installation in an earth-sheltered structure that uses only natural heating and cooling. But if conventional heating and cooling systems are used, all other advantages of earth-sheltering apply.



A.



B.

FIGURE E-3. Summer operation.

SUPPLEMENTAL BIBLIOGRAPHY

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2. Joseph B. Murdoch, Illumination Engineering--from Edison’s Lamp to the Laser, 1985.

3. Heating, Piping, Air Conditioning, “Variable Air Volume (VAV) System Comparison," November 1986, page 186.

4. Heating, Piping, Air Conditioning, “Dedicated Module (DM) Types,” September 1986, page 112.

5. Heating, Piping, Air Conditioning, “Basic Architecture of Dedicated Modules (DMs)," September 1986, page 112.

6. Heating, Piping, Air Conditioning, “Interconnection Reductions by Using Dedicated Modules (DMs)," a and b, September 1986, page 113.

7. Heating, Piping, Air Conditioning, “Integrated Ice Storage/Sprinkler/ Cogeneration/HVAC System Diagram,” May 1986, page 88.

8. Heating, Piping, Air Conditioning, “Redundant Fiber-optic Loop Transmission System, March 1986, page 111.

9. Consulting-Specifying Engineer, “Characteristics of Battery Types,” October 1976, page 99.

10. IEEE Std 587-1980, Guide for Surge Voltages in Low-Voltage Power Circuits, January 1980.

11. AFR 88-15, Criteria and Standards for Air Force Construction.

12. DCA Instruction 350-175-1, Design Practices for High Attitude Electromagnetic Pulse (HEMP) Protection (scheduled to be replaced by MIL-STD-188-125 and MIL-HDBK-423).

*U.S. GOVERNMENT PRINTING OFFICE: 1900--504-034/50045

NOT MEASUREMENT
SENSITIVE

MIL-HDBK-411B
15 MAY 1990

SUPERSEDING
MIL-HDBK-411A
21 MAY 1971

MILITARY HANDBOOK

POWER AND THE ENVIRONMENT FOR SENSITIVE DoD ELECTRONIC EQUIPMENT

(POWER)

VOLUME II

ASMC N/A

AREA SLHC

DISTRIBUTION STATEMENT A. Approved for public release: distribution is unlimited.

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FIGURES (continued)

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FIGURES (continued)

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APPENDIX B FIRE PROTECTION

APPENDIXES (continued)

APPENDIX C PHYSICAL SECURITY

APPENDIX D CHECKLISTS

APPENDIXES (continued)

APPENDIX E DESIGN CONCEPT FOR AN ENERGY EFFICIENT SMALL FACILITY

APPENDIX F SUPPLEMENTAL BIBLIOGRAPHY

FIGURES

FIGURES (continued)

TABLES

1. SCOPE

1.1 Purpose. Volume II of this three-volume handbook provides power system guidance for fixed Department of Defense (DoD) communications, data processing, and information system facilities. The engineering concepts contained in this volume should be selectively applied to the power elements at DoD fixed facilities.

This volume also presents power considerations to use in the engineering of power systems where equipment has been added that is external to a space specifically designed for communications or automatic data processing equipment. Power protection or conditioning for this equipment should follow the guidance provided in this volume. To ensure that environmental control systems for this equipment meet the required parameters, Volume III of this handbook should be consulted.

Volume I addresses these subjects in general terms for the manager or executive. Volume II addresses power system engineering considerations. Volume III addresses environmental control system engineering considerations.

1.2 Applicability. Volume II of this handbook applies to and discusses the following topics.

a. Power requirements and characteristics.

b. Power disturbances, protection, and distribution.

c. Power conversion, conditioning, and regulation.

d. Power system monitoring and control.

e. Auxiliary and alternative power systems.

f. Electromagnetic interference/electromagnetic compatibility (EMI/EMC).

g. Special considerations for computer-based equipment.

1.3 Application Guidance. This handbook can assist in selecting or planning power systems to be installed or upgraded at DoD communications-electronics facilities and related information processing facilities. It applies to engineering during the initial establishment of a facility, or during the upgrade of an existing facility. In addition, this guidance can assist in the engineering of power systems when automation requires using information processing equipment (computers and computer-controlled equipment). This handbook introduces practices and procedures that should be considered during the engineering design phase. This guidance is not to be interpreted as directing that any or all of these control systems should be used at any given facility. Further, it is not to be used solely as a justification for retrofit of existing DoD communications, data processing, and information systems facilities.

1.4 Safety.

1.4.1 Safe work place. Occupational Safety and Health Administration (OSHA) regulations require a safe work place at all times. Although OSHA does not approve specific tools or products, there are Federal specifications for safety tools and they are listed in the appropriate qualified products list (OPL).

OSHA regulations state that no employee shall be required to work in surroundings or under working conditions that are unsanitary, hazardous, or dangerous to health or safety. Employers are required to initiate and maintain programs that comply with this requirement. These programs include inspections of job sites, materials, and equipment. They also ascertain that the use and operation of equipment or machinery is by qualified employees.

1.4.2 Confined spaces. The National Institute for Occupational Safety and Health (NIOSH) estimates that millions of workers may be exposed to hazards in a confined spaces each year. NIOSH'S definition of a confined space is: "a space which by design has limited openings for entry and exit, unfavorable natural ventilation which could contain or produce dangerous air contaminants, and which is not intended for continuous employee occupancy." Investigations of confined-space injuries and fatalities indicate that workers usually do not recognize that they are working in a confined space and may encounter unforseen hazards.

1.4.3 Electrical/electronic equipment. Electrical and electronic equipment normally utilize high voltages and, in some installations, high-energy radiation fields. Safety requirements have been established in individual service documentation that should be reviewed prior to engineering systems in accordance with guidance contained in this volume.

Remember four safety rules:

a. Ground everything that might accidentally become energized.

b. Keep electricity separated from anything that is not to be electrified.

c. Keep heat and sparks (from electrical conductors and equipment) from starting a fire or triggering an explosion.

d. Do not assume electronic equipment is safe. Electrical equipment is dangerous until made or proven safe.

REFERENCED DOCUMENTS

2.1 Government documents.

2.1.1 Standards and handbooks. The following standards and handbooks form a part of this document to the extenty specified herein. Unless otherwise specified, the issue of these documents are those listed in the issue of the Department of Defense Index of Specifications and Standards (DODISS) supplements thereto, cited in the solicitation.

STANDARDS

FEDERAL

FED-STD-1037	Glossary of Telecommun
FIPS PUB 94	Guidelines on Electric, Installations

MILITARY

MIL-STD-188-124A	Grounding, Bonding, and Shielding
MIL-STD-454	Standard General Requirements for Electronic Equipment
MIL-STD-461	Electromagnetic Emission and Susceptibility Requirements for the Control of Electromagnetic Interference
MIL-STD-462	Electromagnetic Interference Characteristics, Measurement of
MIL-STD-882	Standard Safety Program Requirements
MIL-STD-1472	Human Engineering Design Criteria for Military Systems, Equipment, and Facilities

HANDBOOKS

MILITARY

MIL-HDBK-232	Red/Black Engineering and Installation Criteria
MIL-HDBK-412	Site Survey and Facility Decision Handbook for Satellite Earth Stations
MIL-HDBK-413	Design Handbook for High-Frequency Radio Systems
MIL-HDBK-415	Design Handbook for Fiber-Optic Communications Systems
MIL-HDBK-416	Design Handbook for Line-of-Sight Microwave Communications
MIL-HDBK-419	Grounding, Bonding, and Shielding
MIL-HDBK-420	Site Survey Handbook for Communications Facilities
MIL-HDBK-l004/3	Switchgear and Relaying
MIL-HDBK-l004/4	Electrical Utilization Systems
MIL-HDBK-1195	Radio Frequency Shielded Enclosures

(Unless otherwise indicated, copies of federal and military specifications, standards, and handbooks are available from the Standardization Documents Order Desk, Bldg. 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.)

2.1.2 Other Government documents, drawings, and publications. The following other Government documents, drawins, and publications form a part of this document to the extent specified herein. Unless otherwise specified, the issues are those cited in the solication.

DODISS	Department of Defense Index of Specifications and Standards
DoD 4630.7-M	Doll Construction Criteria Manual Major Fixed Command, Control, and Communications Facilities Power Systems Design Features Manual
CPG 2-17	Electromagnetic Pulse Protection Guidance (Published by Federal Emergency Management Agency)

(Copies of DCID 4630.7-M (on a subscription basis) are available from the Standardization Documents Order Desk, Bldg. 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094. Copies of the DODISS are available on a yearly subscription basis either from the Government Printing Office for hard copy, or microfiche copies are available from the Director, Navy Publications and Printing Service Office, 700 Robbins Avenue, Philadelphia, PA 19111-5093.)

2.2 Other publications. The following documents form a part of this document to the extent specified herein. Unless otherwise specified, the issues of the documents which are DoD adopted are those listed in the issue of the DODISS cited in the solicitation. Unless otherwise specified, the issues of documents not listed in the DODISS are the issues of the documents cited in the solicitation.

NATIONAL FIRE PROTECTION ASSOCIATION

NFPA-30	Flammable and Combustible Liquids Code
NFPA-37	Stationary Combustion Engines and Gas Turbines
NFPA-70	National Electrical Code

(Applications for copies should be addressed to the National Fire Protection Association, Batterymarch Park, Quincy, MA 02269.)

AMERICAN NATIONAL STANDARDS INSTITUTE

ANSI-C2	National Electrical Safety Code
ANSI-C62.41	Category A & B Guidelines for Surge Voltage
ANSI-C84.1	Voltage Ratings for Electric Power Systems and Equipment (60 Hz)
ANSI/IEEE STD 142	Recommended Practice for Grounding of Industrial and Commercial Power Systems
ANSI/IEEE STD 241	IEEE Recommended Practice for Electric Power Systems in Commercial Buildings
ANSI/IEEE STD 446	IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems
ANSI/IEEE STD 587	IEEE Guide for Surge Voltages in Low Voltage AC Power Circuits

(Applications for copies should be addressed to the American National Standards Institute, 1430 Broadway, New York, NY 10018-3308.)

INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS (IEEE)

IEEL STD 242	IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems

(Applications for copies should be addressed to the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, Piscataway, NJ 08854-4150.)

UNDERWRITERS LABORATORIES

UL STD 1449	Standard for Transient Voltage Surge Suppressors

(Applications for copies should be addressed to Underwriters Laboratories Inc., 333 Pfingsten Rd., Northbrook, IL 60062.)

(Non-Government standards and other publications are normally available from the organizations that prepare or distribute the documents. These documents also may be available in or through libraries or other informational services.)

2.3 Order of precedence. In the event of a conflict between the text of this document and the references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained. In the event of a conflict between this handbook and another military handbook, the more specific handbook shall normally take precedence. For example, at a satellite earth station, the military handbook on that subject (MIL-HDBK-412) would take precedence. Similarly, a conflict concerning grounding, bonding, and shielding procedures would be resolved in favor of the handbook that deals specifically with that subject, in this case, MIL-HDBK-419.

3. DEFINITIONS

3.1 Acronyms and abbreviations. For acronyms and abbreviations used in this handbook, refer to Federal Standard 1037A (Glossary of Telecommunication Terms), except as listed below for the purpose of this handbook.

ANSI - American National Standards Institute
BIL - Basic insulation level
Btu - British thermal unit(s)
CFM - Cubic feet per minute (or ft/min)
CISPR - International Special Committee on Radio Interference
DCA - Defense Communications Agency
DoE - Department of Energy
EMC - Electromagnetic compatibility
EMI - Electromagnetic interference
EMP - Electromagnetic pulse
ESD - Electrostatic discharge
FIPS - Federal Information Processin Standards
GFCI - Ground fault circuit interrupfer
HEMP - High altitude electromagnetic pulse
IC - Interrupting capacity
IEEE - Institute for Electrical and Electronics Engineers
LPG - Liquid petroleum gas
MCC - Motor control center
MDH-EMP - Magnetohydrodynamic electromagnetic pulse
MG - Motor generator
MOV - Metal oxide varistor
MTBF - Mean-time-between-failure
NEC - National Electric Code
NEMA - National Electrical Manufacturers Association
NFPA - National Fire Protection Agency
PF - Power factor
PWM - Pulse-width modulation
SCR - Silicon-controlled rectifier
SE - Shielding effectiveness
SGEMP - System-generated electromagnetic pulse
THD - Total harmonic distortion
UL - Underwriters Laboratories
UPS - Uninterruptible power systems
VCCI - Voluntary Control Council for Interference
VESDA - Very early smoke detection apparatus
WDM - Wavelength-division multiplexing

3.2 Terms and definitions. For definitions of the terms used in this handbook, refer to Federal Standard 1037 (Glossary of Telecommunication Terms), except as listed below, which are uniquely defined for the purpose of this handbook.

arrester	A protective device used as a bypass to ground for transients resulting from such things as lighting or EMP which are coupled to an antenna or other conductor.

cogeneration	The simultaneous generation and use of electrical power and heat energy from a single fuel source.
dry-type transformer	A transformer which is cooled by the natural or forced circulation of air, as opposed to a liquid.
ductwork	A system or network of ducts used for the distribution or exhaust of air, also used to distribute power and communicating conductors or cables throughout a facility.
fault current	The current that may flow in a circuit as a result of specified abnormal conditions.
ground-fault circuit-interrupter	A device to protect personnel by de-energizing a circuit or part of a circuit, within an established period of time, when the current to ground exceeds a set value which is less than the supply protection value.
grounded conductor	A conductor in a power distribution system (usually designated the neutral) which is intentionally earth grounded, either solidly or through a grounding device. The outer jacket of the conductor, if insulated, is white in color.
grounding conductor	A conductor which carries no current under normal conditions. It serves to connect exposed metal surfaces to an earth ground to prevent hazards in case of breakdown between current carrying parts of a power distribution system and the exposed surfaces. The outer jacket of the conductor, if insulated, is green in color, with or without a yellow
intrinsically safe	The incapability of devices to release sufficient energy to cause ignition of a specific atmospheric mixture under normal or specified abnormal conditions.
joule	The energy required to transport one coulomb (metric unit of electrical charge equal to the amount of electricity transferred by a current of one ampere in one second) between two points having a potential difference of one volt.

load sheading	The capability of an electrical distribution system to remove noncritical loads during power shortages.
nanojoule	One-billionth of a joule.
one-line power diagram	A diagram which, by means of single lines and graphic symbols, shows the layout of an electrical circuit and the components used therein.
power factor (PF)	The ratio of active power and apparent power.
protective relay	A relay (mechanical) or solid state) used to detect abnormalities in a power system or components and initiate appropriate warning or control action.
resistance	A measure of the ability of a material or substance to impede or insulate the flow of heat. Resistance is the reciprocal of conductivity and conductance. In the electrical sense, the property of a substance which impedes current and results in the dissipation of power.
suppressors	Devices or circuits used to reduce or eliminate unwanted signals, noise, or interference. Suppression methods include shielding, filtering, grounding, relocation, and redesign.
switching transients	An over-voltage in an electrical circuit, caused by a switching action in the power grid or in user equipment.
transient	A momentary surge on a communication or power line that may produce false signals or triggering and can cause insulation or component upset or failure.
transient voltage	Generally used to describe a momentary surge in an electrical circuit that exhibits a fast-rising current and voltage waveform.
voltage sag	Generally used to describe a momentary voltage reduction in a power distribution system of 10-35 percent below nominal level.
voltage surge	Generally used to describe a momentary voltage increase in a power distribution system of 10-35 percent above nominal level.

4. GENERAL REQUIREMENTS

See volume I.

5. DETAILED REQUIREMENTS.

5.1 General. The overall design objective is to ensure adequate mission support with a reliable, cost-effective power distribution system. All estimates of system cost effectiveness must include long-term projections of public utility rates, fuel, and maintenance costs. Although direct current (de) is used extensively in DoD facilities, the primary concern in electrical design is the generation and distribution of alternating current (ac). Some of the advantages of using ac power distribution systems are: (1) the voltage is easily transformed to match the load; (2) the ac line frequency (50, 60, and 400 Hz) provides a stable time standard for clocks, motors, and similar devices; and, (3) ac line losses are easier to control. From the cost standpoint, it is very important that DoD facilities have an efficient mechanical and electrical design. In fact, the mechanical and electrical system costs may exceed 50 percent of the total facility cost. As a result, users, designers, architects, and contractors invariably look for cost savings in mechanical and electrical installations during all phases of facility development.

5.2 System design. The designer of the power system for a DoD information processing system must consider the following:

a. Primary power generation (source).

b. Power transmission (grid).

c. Power disturbances (transients, sags, and surges).

d. Power protection (arresters).

e. Ac and dc power distribution (within facility).

f. Overcurrent protection and coordination (fuses, circuit breakers, and relays).

g. Transformers (voltage matching and isolation).

h. Power conditioning (isolation, conversion, and UPS).

i. Auxiliary power source (engine generators).

j. Alternative power sources (solar, hydro, fuel cells).

k. Life safety (equipment grounding and GFCIS).

l. Special considerations for computer-based equipment.

5.2.1 Primary power generation. This portion of the design examines the source of electricity that supplies the DoD facility. The characteristics of the electrical power needed for the facility should be compared to those available from local public utilities. The characteristics to be examined are: reliability, voltage, frequency, number of phases, and available kilowatts (kW). In some locations, considering just these characteristics will result in a decision that self-generation (cogeneration) is the best solution.

5.2.2 Power transmission. Once the source(s) of power is determined, then the method of transmitting power to the facility is considered. The level of transmitted voltage, distance from generation station or substation, other users on the feed, susceptibility to disturbance, and availability of multiple power sources or feeds are among the factors to investigate. Above-ground power lines may also have undesirable effects on power quality because they exhibit increased vulnerability to accidents, weather phenomena, and vandalism. However, the increased cost of underground transmission lines generally results in overhead construction to the substation. See table I for some typical properties of above-ground power transmission lines. Whenever possible, the building entrance (service conductors) should be underground from the serving transformer location. For example, underground power runs of about 30 meters can result in as much as a 3-to-1 reduction in transient levels and in some other types of interference. Power for the facility should be obtained from two separate primary power sources. Then, if one source fails, the other source will continue to provide power to the facility. Reliability of the power provided should be evaluated by studying the outage statistics over the past few years. This includes: the average number of outages per year, the time of year when most outages are experienced, cause of the outages, and average restoral time. It is also important to note any trends toward frequent surges or sags.

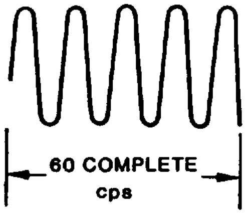
Present commercial power users should be asked to assess the quality of local power quality. This data is instrumental in determining the need for emergency power. Note that requests for upgraded power distribution will almost always result in extra charges to the customer. If a DoD electronics facility is to be located on or near an existing military installation, then the local civil engineer will furnish information or power quality.

5.2.3 Power disturbances. Protection from power disturbances is a critical element in power system design. Power disturbances may occur in the form of sags, surges, frequency variation, high or low voltage, outages, or harmonic distoration as shown in figure 1. Portable power-disturbance monitor equipment records,and the one-line drawing (see 5.2.5.1) developed during the site survey phase should be the basis for the facility power protection design. If this site survey data is incomplete, or over a year old, then a local area survey should be made to evaluate heavy industrial operations that can cause transients, the frequency and severity of lightning, or any other conditions that might cause power disturbances. The electrical power distribution system should at least meet the standard voltage ranges in ANSI C84,1, Also, the mission statement should be reviewed to determine if a facility must also withstand the effects of EMP. DCA Instruction 350-175-1, 4 June 1986 (until superseded by MIL-STD-188-125 and MIL-HDBK-423) contains HEMP survivability information for selected command, control, and communications facilities.

TABLE I. Some typical properties of above-ground power lines.

Voltage (kV)	Basic Insulation Level (kV)	Height of Lowest Conductor (ft)		Span (ft)		Typical Length	Type
		Wood Poles	Steel Tower	Wood Poles	Steel Tower		
2.4	45	25-35		160-200*		0-3	Distribution
4.8	60	25-35		100-200*		0-5	Distribution
7.2		30-40		100-200*		1-10	Distribution
12.5	95	30-40		100-200*		5-20	Distribution
23	150	30-40		200*		5-30	and
34.5	200	40		300*		10-40	Subtransmission
69	350	45	40-50	500	600	25-100	Transmission
115	550	50	40-60	600	700	25-100	Transmission
138	650	50	50-80	600	800-900	25-140	Transmission
161	750	50	50-80	600	900-1000		Transmission
230	1050		60-100		900-1000		Transmission
287.5	1300		70-120		900-1000		Transmission

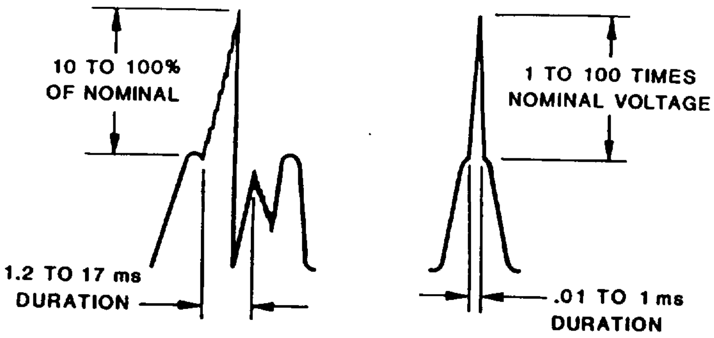
* Longer spans are often used in rural areas.



1 CYCLE = 16.7 ms

CLEAN POWER

NO MYSTERIOUS DATA **GARBLING**
& UNEXPLAINED HARDWARE
MALFUNCTIONS

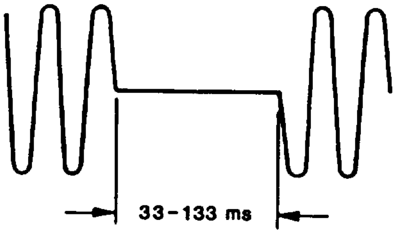


POWER FACTOR
CORRECTION TRANSIENT

SPIKE TRANSIENT
HIGH VOLTAGE

B. MOMENTARY TRANSIENTS

CAN RANDOMLY DESTROY DATA &
SEMICONDUCTOR COMPONENTS



D. MOMENTARY POWER INTERRUPTIONS

CAN CAUSE COMPLETE LOSS OF ACTIVE
MEMORY & SEVERELY STRESS HARDWARE
COMPONENTS, PARTICULARLY IF POWER IS
ALLOWED TO SURGE BACK AUTOMATICALLY

C. VOLTAGE SAGS & SURGES

CAN CAUSE DATA GARBLING &
STRESS HARDWARE COMPONENTS

FIGURE 1. Graphic explanation of power quality terms.

5.2.4 Power protection. Power feeder(s) to a facility must be carefully studied to determine the type and level of overvoltage protection (arresters) needed. This survey must include arresters provided by the utility company. Power grid overvoltages have three basic causes: lighting, switching, and inadvertent contact with a circuit carrying higher voltage. Power grid protectors are basically lighting arresters. Most of those in use are a form of the basic circuit shown on figure 2. In new lower voltage (under 20 kV) distribution, this type of arrester is being replaced by metal oxide varistors (MOVS) that rely on the material, rather than spacing of the air gap, to determine firing point. The MOV-type arresters tend to fire faster and are typically selected with a firing point of about 20 percent higher than the distribution voltage. The most important concept in protection of equipment from power source transients is “progressive arresting”. Simply stated, this means that higher joule-rated protective devices are applied at the building power entrance, and lower-rated devices, which are also physically smaller, are applied at building power distribution panels. Even lower joule-rated devices are used at the chassis or circuit-board level. Each arrester application point should be separated from the other by approximately 2 meters (6 feet) to accomplish the desired transient reduction. It is also helpful in device selection to know the threat to a facility (or system) by the mode of transient propagation. For example, transients that appear across the current-carrying conductors of a power line (figure 3) are referred to as a normal or transverse mode. A power-line transient between a current-carrying conductor and earth (ground) is referred to as the common mode. Special care should be taken to see that all power distribution cabinets and outlets are grounded as required by the National Electric Code (NEC) and MIL-HDBK-419. Even though permitted in the NEC, metallic conduit alone must not be substituted for the “green wire” ground in DoD installations. One of the main concerns for the DoD facility designer is the type and level of protection installed by the utility company at the serving substation(s). In addition to obtaining overvoltage and overcurrent protection information on the substation(s), the available short-circuit current must be determined. This is the first step in developing the one-line power diagram (see 5.2.5.1) used to coordinate all facility power protective devices such as circuit breakers, protective relays, and fuses. Paragraph 5.5.6 of this handbook provides information on protective device selection and coordination.

5.2.5 Low voltage ac and dc distribution. Here, the designer should consider the various categories of service needed in the facility. The includes the most cost-effective layout for reliable service with minimal complexity. The one-line power diagram which is discussed in the following paragraph is used to determine location and rating of power distribution centers, transformers, breakers, and other protective devices. Where dc distribution is required, the design should include the use, location, and installation of rectifiers, battery systems, and dc buses. Dc power distribution requires more careful planning and design than ac systems. In dc systems, poor design can result in an unacceptable voltage drop or poor power supply regulation. Ac and dc power-distribution layouts, such as simple radial, mixed radial and parallel, primary selective, primary loop, etc., are covered in 5.7.

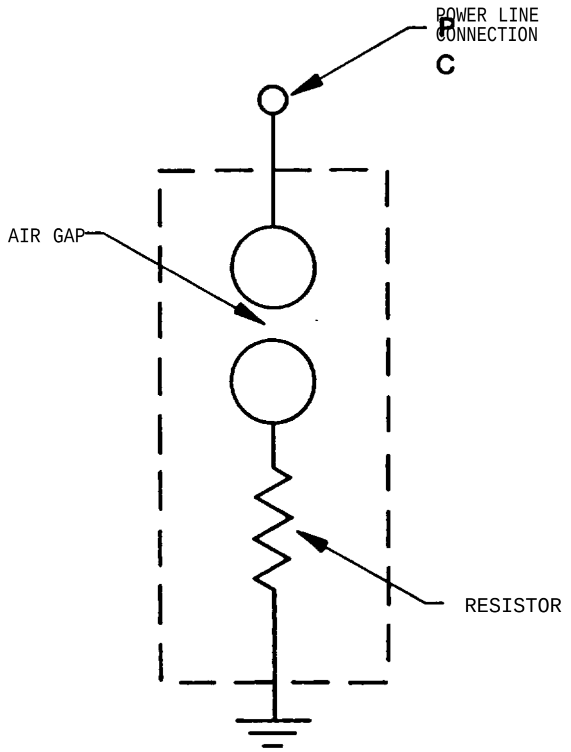


FIGURE 2. Basic lighting arrester.

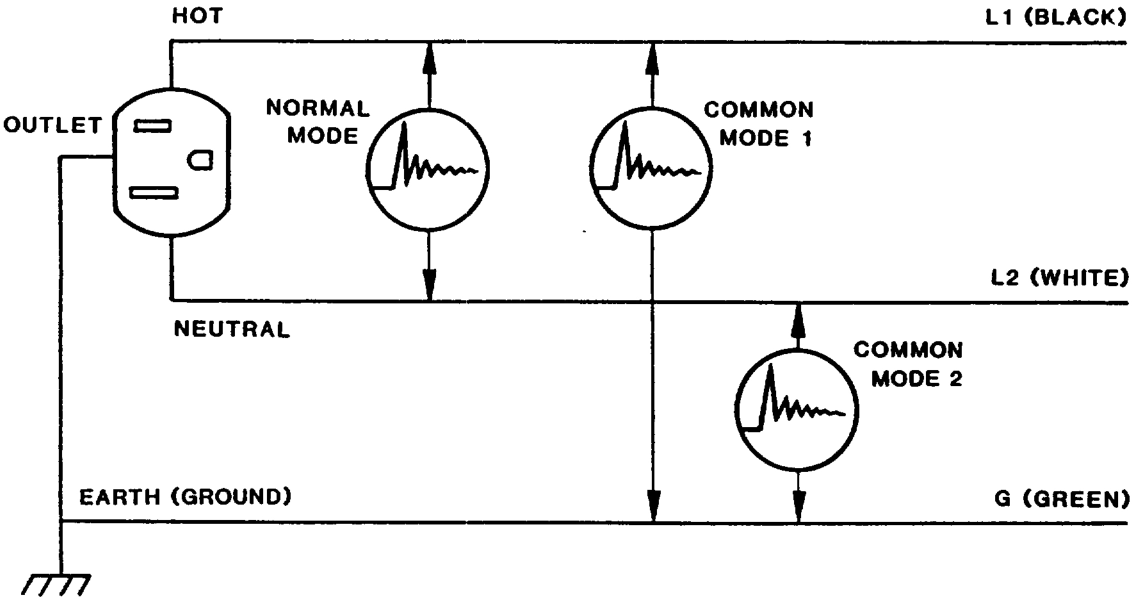
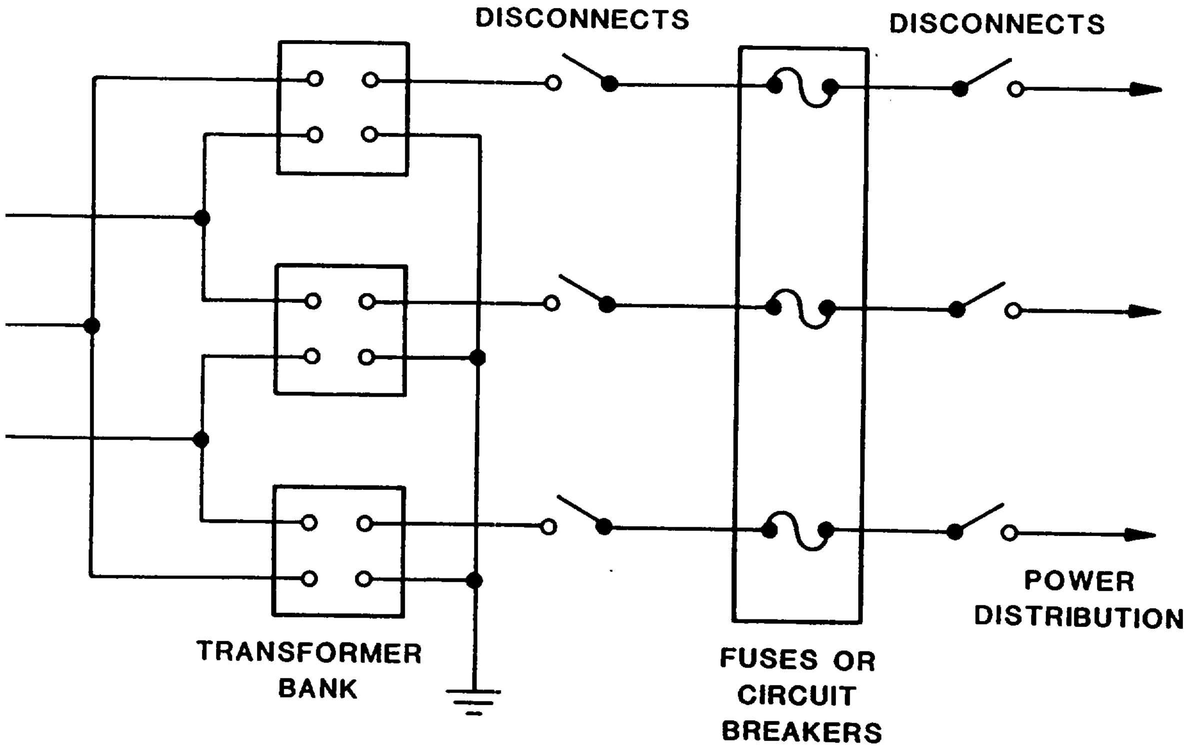


FIGURE 3. Common/normal mode transients in 120-V single-phase power distribution.

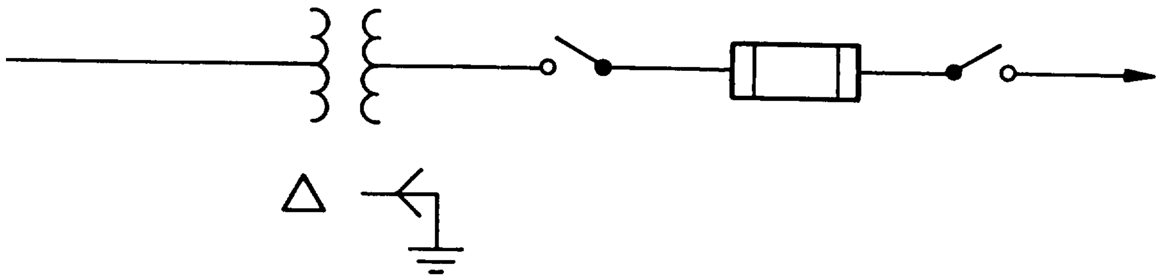
5.2.5.1 One-line power distribution diagrams. One-line, or single-line, diagrams are used to graphically simplify complicated power distribution systems for further study. Most power systems consist of three or more conductors, circuit breakers, and disconnects, as shown on figure 4a, with the equivalent one-line diagram on figure 4b. One-line diagrams are used extensively, and it is up to the individual to visualize that each component is actually in multiples. The first step in developing a one-line power diagram is to establish loads and their locations by contacting the engineers and users involved in the design. Next, the incoming voltage level is obtained from the serving utility company and the required facility distribution voltage from the equipment specifications. Equipment current loads or power ratings must also be determined. The last step is to determine system reliability requirements and then decide whether simple radial, primary selective, or secondary selective distribution best meets the reliability requirements. These distribution arrangements are discussed in 5.7 of this volume.

5.2.6 Overcurrent protection. A less understood part of facility power design is the proper selection and coordination of overcurrent protectors. Proper protective device location and coordination prevents equipment damage, reduces downtime, and promotes life safety. A fault-proof power system design is impossible, so a certain number of faults must be tolerated during the life of a system. The main types of faults on a three-phase system are: (1) shorts between phases, (2) all phases shorted to ground, (3) a single phase shorted to ground, and (4) arcing to nearby objects. Full-scale "bolted" short circuits are uncommon, but DoD power protection designs must consider this possibility. When a fault occurs, the flow of current to the faulted circuit must be interrupted immediately without affecting power to other areas. The application of overcurrent protective devices is interleaved throughout this volume; however, current publications on overcurrent protection from the IEEE, NFPA (NEC), and the UL should be consulted for additional technical information.

5.2.6.1. Protection devices. Due to the possibility of equipment failure or human error, it is necessary to provide overcurrent protective devices. These devices minimize damage when a failure occurs through isolation of the affected circuit, while maintaining service to the rest of the system. Protective relays, fuses, and circuit breakers are examples of devices used to provide this type of protection. One special relay type that can be used to protect motors, power filters, transformers, and personnel is the ground protective relay. In the equipment case, the relay detects failure of the insulation of a machine, transformer, or other apparatus to ground. personnel safety application, they are called ground-fault circuit interrupters (GFCI) and are required by the NEC in hazardous locations. Other protective devices limit transients by attenuation (filters) or diversion (voltage clamping). Although brief, transients as small as one nanojoule of energy are sufficient to upset transistors, integrated circuits, and semiconductors. Because there are so many sources for potentially destructive transients, the best solution is to isolate the critical technical load (see figure 5) from the power grid. Even when this load had been isolated, it is still desirable to suppress transients to all of the station load. This reduces the chance of damage to nontechnical equipment or to the isolation equipment itself.



A.



B.

FIGURE 4. One-line diagram concept.

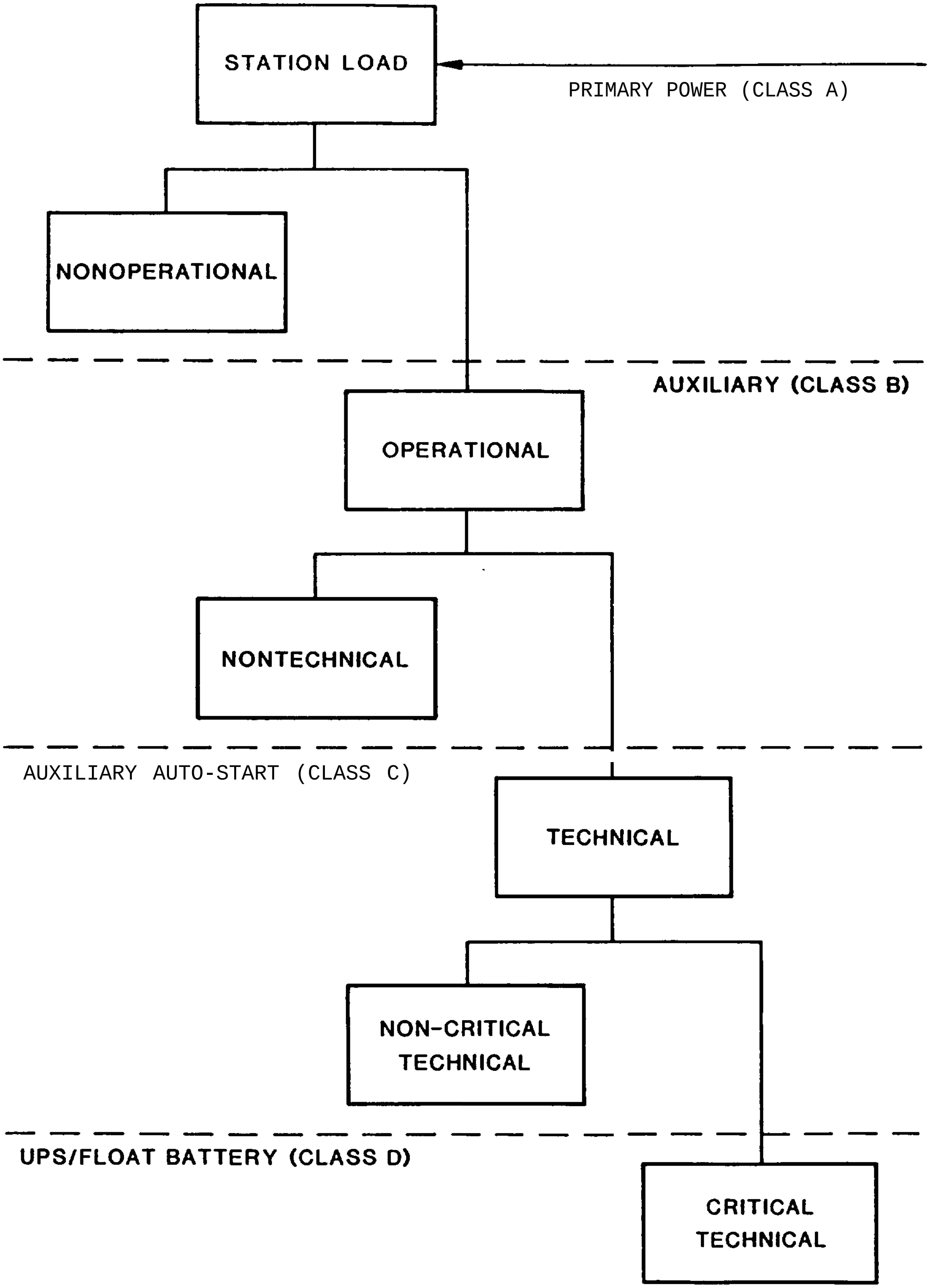


FIGURE 5. Power hierarchy diagram.

5.2.6.2 Fuses. Within the first half cycle (1/120th of a second) of an electrical fault, surge currents in a power distribution system have been observed to be in the 200,00-amp range. With these high surge currents to consider, downstream circuit protection is extremely important. It is also important to understand what available fault current really means. of the current limiting device is not necessarily determined by the facility distribution system because the utility may have sized their distribution to serve several local users. This means that the available fault current is increased proportionally. The job assigned to the current-limiting device (fuses, circuit breakers, and relays) is to force the current to zero before its normal time. In the case of a 60-Hz line frequency, the design objective is to accomplish this prior to the first zero crossing (or 8.3 milliseconds after detection of a fault). The limiting device must withstand these high currents without being physically destroyed. The two basic types of fuses are current limiting and noncurrent limiting. Noncurrent-limiting fuses are usually the replaceable type operating in one or two cycles, where current-limiting types are very fast -- acting in less than a quarter cycle. Interrupting ratings of both types are expressed in symmetrical amperes, but they are capable of interrupting 1.6 times their rating on asymmetrical fault currents. Fuses continue to have a very definite role in modern power distribution and can be used to protect against the possibility of erratic or slow operation of circuit breakers. Fuses for transformer protection have recently been developed that have an interrupting module and a solid-state control module. The interrupting module only reacts to a fault current detected by the control module. They are available for the 4- to 25-kV range and feature extremely fast reaction to overcurrent conditions. Section 240 of the NEC addresses the location and application of protective devices.

5.2.6.3 Circuit breakers. Circuit breakers classed as “current limiting”, depend on electromagnetic repulsion to interrupt a fault current. With a rapidly increasing current through the breaker, the opposing magnetic fields move the contracts apart quickly. In fact, to meet specifications, the action must occur in less than 8.3 milliseconds. Although circuit breakers are rated by the current they will interrupt called interrupting capacity (IC), system voltage is of equal importance as the stated current rating, which must change with a change in voltage. Current limiting is designed to interrupt the circuit before peak current occurs. This means that if an underrated breaker is specified, the fault current may physically destroy the protective device. The main advantage of circuit breakers over fuses is the ability of a quick reset following fault identification and clearance. major disadvantage is the slower reaction time of most circuit breakers. Solid-state circuit breakers protect against such things as jammed machinery, single- or multiple-phase failure, and phase sequence reversal. Vacuum- and oil-surrounded breaker contacts are used in some high voltage applications to help extinguish the arc that results during contact opening and closing actions. Breakers that have been installed for several years are notorious for failure to open when a fault occurs. Most of these failures can be traced to improper maintenance or installation in a corrosive location. The solution to providing a safe, fault protection system is to use the correct protector for a specific location or function. This solution starts with the reparation of a one-line power diagram for the facility. When this drawing has been completed, an analysis is made at typical points where a short might occur. This diagram, coupled with knowledge of available fault current and equipment characteristics, permits selection of the correct current-limiting device. The trend in custom circuit-breaker design is away from analog to newer digital devices. The digital versions are programmable and can provide integral ground fault protection. Several sections of the NEC pertain to the application and selection of circuit breakers. ANSI, IEEE, and NEMA have all produced standards and articles on the subject.

5.2.6.4 Protective relays. Protective relays are also used to limit current, operate power breakers, and react to abnormal voltage, frequency, or phase conditions. Most versions of protective relays are equipped with adjustable thresholds. Electromechanical protective relays are used extensively in multiphase motor protection, in automatic transfer switches, abd ground fault (current) detection. Some of the significant improvements offered by solid-state protective relays over electromechanical versions are listed in Table II. Additional applications of protective relays will be discussed in 5.10.1.

TABLE II. Advantages of solid-state protective relays.

Dynamic reaction to power changes
Adjustable settings (thresholds)
Low power drain (saves on instrument transformer costs)
Integral test circuitry
Take up less panel space
Can be equipped for remote programming
Immunity to seismic activity
Consistent performance

5.2.6.5 Surge suppressors (arresters). Previous discussion extolled the virtue of solid-state protective devices, but these devices are in intimate contact with the power distribution system. This means that transient protection in the form of surge suppressors must be installed ahead of solid-state protective devices on the power distribution system to ensure survivability. Most solid-state protective relays and circuit breakers have internal bipolar zeners or MOVS to protect circuitry from low-level transients. Surge suppressors (arresters) are available to protect everything from high-voltage power distribution systems down to the smallest electronic component (circuit board level). In the selection process for the correct protection devices, the designer must start with the generalized characteristics of the expected threat from lighting or EMP, and due to major differences in reaction time of the various types of protectors, threat waveshape definition is extremely important. A surge impinging on a power system and reacting with natural system resonances can result in an oscillatory surge. A circuit reacting to a unipolar surge or transient, tends to produce an oscillating, decaying, polarity-reversing wave such as that shown on figure 6. IEEE and ANSI standards define several waveforms that can be used for testing of devices. These waveforms are for different environments, but their definitions are based on averages; thus industry commonality for device testing is assured. Refer to table III for additional definitions. The facility one-line power diagram can be used to determine where properly rated protective devices are to be placed. "Properly rated" refers to device voltage rating, reaction time, and energy handling capability (usually stated in joules).

5.2.7 Tranformers. Transformers are an integral part of power systems. Transformers are used to step down the transmission voltage to the voltage used by the load, and to isolate the load (or metering) from line disturbances. Depending on company policy, step-down transformers may or may not be supplied by the serving utility. Isolation transformers, or dry-type transformers for outlet voltages, may be needed for individual load centers in the facility.

5.2.8 Power conditioning. Power conditioning compensates for anomalies in the supplied power, that adversely affect operation. Basically, these are: fluctuations in voltage and frequency, a change of the power system harmonics, or noise. These topics are covered in 5.9 of this handbook.

5.2.9 Auxiliary power sources. Certain DoD facilities require continuous operation. In some locations, auxiliary (emergency) power sources must be available when prime power is interrupted. Therefore, the design must include the type of auxiliary power needed, time required to restore power, and the amount of time the selected power unit can sustain the critical load.

5.2.10 Alternative power sources. The energy crisis of the 1970s was a grave reminder that fossil fuels are nonrenewable, can be expensive, and are often polluting. The realization that continued dependence using fossil fuels to meet the rapidly expanding demand for electrical power is not practical and is potentially dangerous has stimulated the search for realistic alternative power sources.

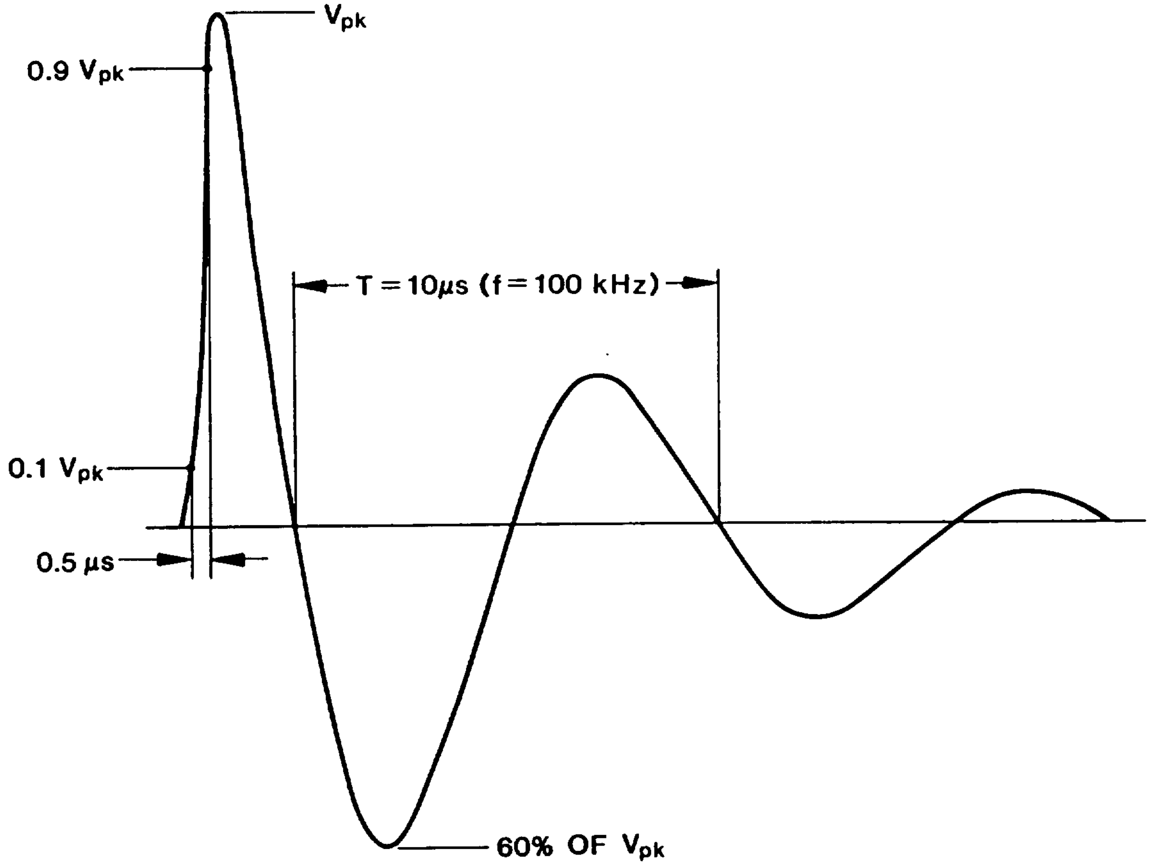


FIGURE 6. Representative indoor surge waveform.

TABLE III. Surge voltages and currents representing the indoor environment.

LOCATION CATEGORY	COMPARABLE TO *IEC 664 CATEGORY	IMPULSE		TYPE OF SPECIMEN OR LOAD CIRCUIT	ENERGY (JOULES) DEPOSITED IN A SUPPRESSOR WITH CLAMPING VOLTAGE OF	
		WAVEFORM	MEDIUM EXPOSURE AMPLITUDE		500 V	1000 V
					(120 V system)	(240 V system)
A. Long branch circuits and outlets	II	0.5 s - 100 kHz	6 kV	High impedance	--	--
			200 A	Low impedance	0.8	1.6
B. Major feeders short branch circuits, and load center	III	1.2/5 s	6 kV	High impedance	--	--
		8/20 s	3 kA	Low impedance	40	80
		0.5 s - 100 kHz	6 kV	High impedance	--	--
			500 A	Low impedance	2	4

*International Electrotechnical Commission energy sources are defined as any sources other than fossil fuels. Ongoing research and development efforts are addressing such sources as: the sun, renewable alternate fuels, fuel cells, and small nuclear reactors. hydroelectric power plants, which use water-driven turbines to generate electricity, are used by certain commercially- or publically-owned companies. Reservoirs and dams are commonly used to provide an uninterrupted flow of water. Some hydroelectric plants are seasonal and provide power on a supplemental basis. Power generation by wind and ocean-wave motion” are considered to be from solar energy. Continuing studies address the harnessing of tidal energy in areas where large tidal variations are experienced. Energy extraction methods are essentially the use of turbine generators driven by the ebb and flow of tidal water. Power generation from naturally occurring local resources is very attractive at remote and isolated locations, especially those without access to a commercial grid or which would require fuel to be transported over long distances or under adverse conditions. Storage batteries and flywheels are also regarded as alternative energy sources, better suited to UPS applications (see 5.9). The use of renewable, alternative power sources at DoD facilities should always be considered to ensure that cost reduction, fuel savings, and environmental impact are part of their design.

5.2.10.1 Solar power. The amount of energy from the sun reaching the earth each year has been estimated to exceed man' s current annual energy consumption by some four orders of magitude. Solar energy is inexhaustible, requires no fuel, does not pollute the environment, is available almost everywhere, and cannot be controlled by other nations. The use of solar radiation to generate electrical power is rapidly evolving from the development stage to practical and economical applications. Turbogenerators, currently employing the heat produced by burning coal, oil, and natural gas, can be powered by the sun in a process called solar thermal energy conversion. Similarly, small power requirements are being met through the use of solar heat engines. Photovoltaic devices (solar cells) are used to generate electricity for space vehicles and at remote and unattended terrestrial locations, as well as to supply power for calculators, cameras, and watches. The availability of solar radiation at a particular location is the prime consideration for proposed application at a site. Therefore, the amount of solar energy that the site receives must be thoroughly researched. Normally, the intermittent character of sunlight requires that some type of energy storage is available to handle periods of darkness and cloud cover. Batteries provide limited electrical power storage and thermal mass is used effectively to store heat. Accordingly, the high reliability needed in the operation of most large DoD facilities precludes the use of solar energy as a sole source. However, the, obvious economical advantages of using the sun as a supplemental source or in special applications should always be considered.

5.2.10.1.1 Photovoltaic electrical power. Photovoltaic solar cells have been used to generate electricity since their invention by Bell Laboratories in 1954. Certain semiconductor materials, such as cadmium sulfide, cadmium telluride, and silicon can produce a voltage when exposed to light. The most commonly used material has been silicon in the expensive, pure crystalline form. Solar energy, in the form of photons, causes some of the four electrons in the valance bands of silicon atoms to move out into conduction bands. These freed electrons are then available to form an electric current. Solar cells have n-p junctions, like transistors, that provide a path for the freed electrons and develop a dc voltage. Figure 7 is a diagram of a typical silicon solar cell.

a. Each cell produces approximately 0.5 volt under bright sunlight. However, the current increases with light intensity, cell surface area, and cell efficiency. The maximum output power of solar arrays is around 150 watts per square meter. The cells are configured in series and parallel arrangements, called modules. Modules are the basic building blocks that form arrays designed for specific utilization voltages. Figure 8 shows how a solar array might be installed at a remote microwave radio location. Individual solar cell efficiencies are small, typically in the area of 15 percent for crystalline silicon devices. This is because only those photons within a given energy range (called bandgap) of the semiconductor material (1.1 electron volts for silicon will cause the displacement of electrons.

b. In efforts to reduce costs, other less expensive materials, such as amorphous silicon and silicon alloy thin-films are being used. The inherently low efficiencies of these materials, (4 - 6 percent) are being improved upon by innovative fabrication techniques. For example, silicon is alloyed with other materials to form semiconductors with different bandgaps. These semiconducting materials are then combined to form multiple-junction solar cells with an expanded bandgap, which makes effective use of a greater portion of the light spectrum. The result is lower-cost solar cells, with efficiencies approaching those of the more expensive silicon crystal devices.

c. The application of current photovoltaic technology to meet large power requirements involves solar arrays of considerable size. Systems capable of generating several megawatts of electricity currently exist, with arrays that cover more than 100 acres. Buildings that contain inverters to convert dc from the solar cell array to ac, as well as other system control functions, are located near the center of the array to minimize cable losses. Large solar cell arrays can also present security problems. The need for large physical space will decrease as photovoltaic technology improves. Concurrently, the power demands of many electronic devices are being lowered by the use of newly discovered semiconductor materials and fabrication techniques to create large scale integrated circuits. Recent advances in superconductor physics promise the availability of materials with almost no electrical resistance. These materials will revolutionize energy transmission, and both the power and electronics industries. Lower overall electronic-system power demands make the application of photovoltaic technology very attractive, using abundant and free solar energy.

5.2.10.1.2 Solar thermal-energy conversion. This method of electrical power generation involves the use of sunlight to heat a fluid which drives a heat engine or generator. Solar thermal-energy conversion systems vary in size from small heat engines for small loads to large central plants for major installation.

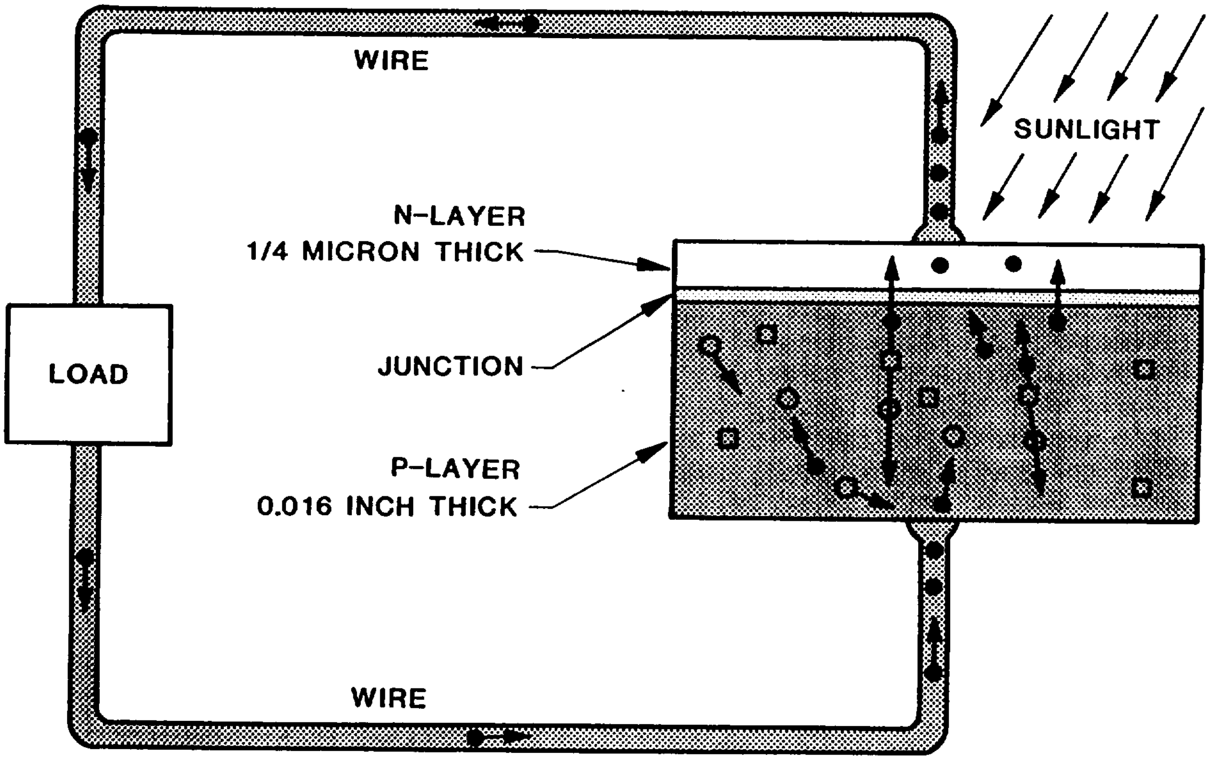


FIGURE 7. Silicon solar cell.

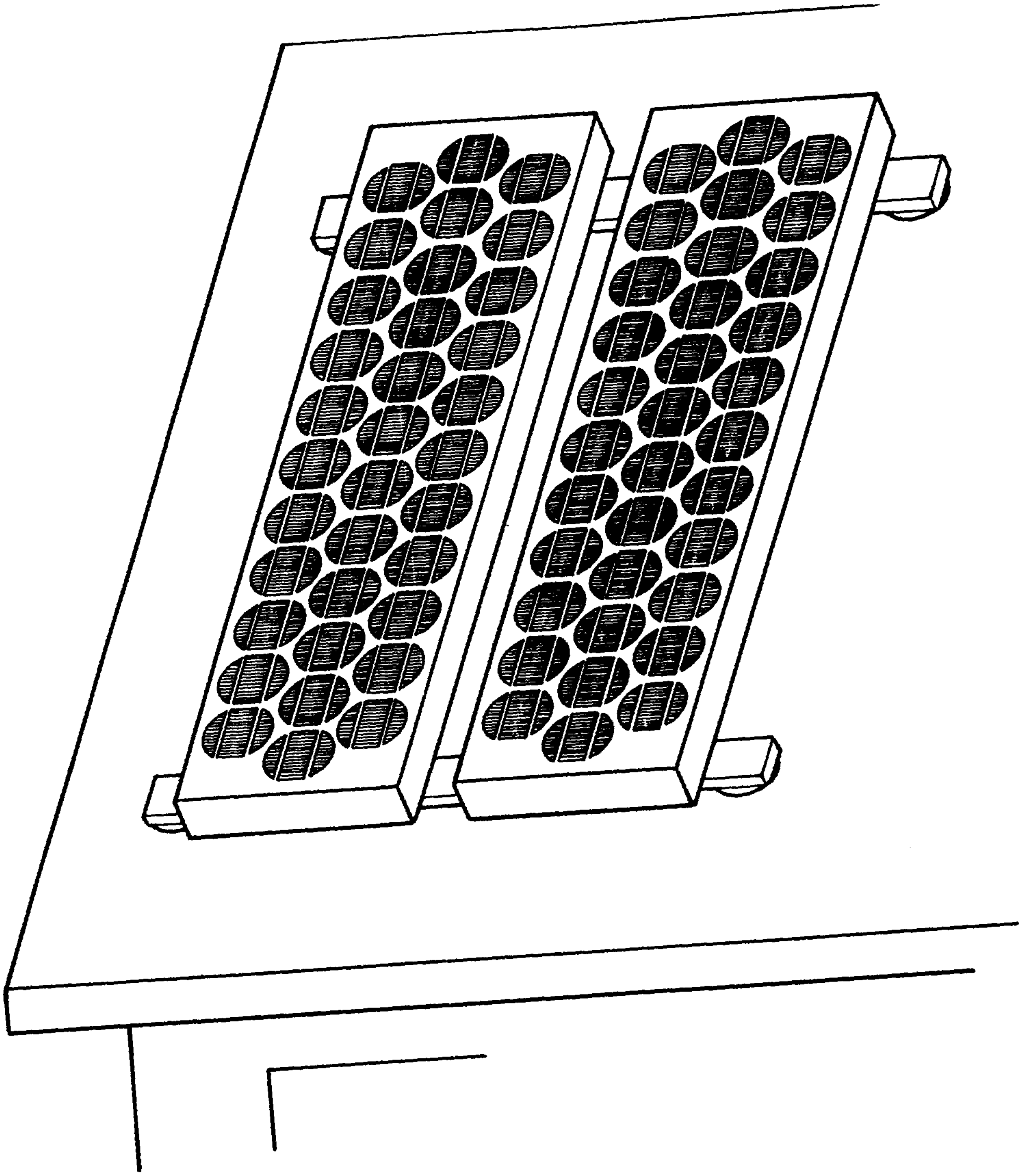


FIGURE 8. Phovoltaic array.

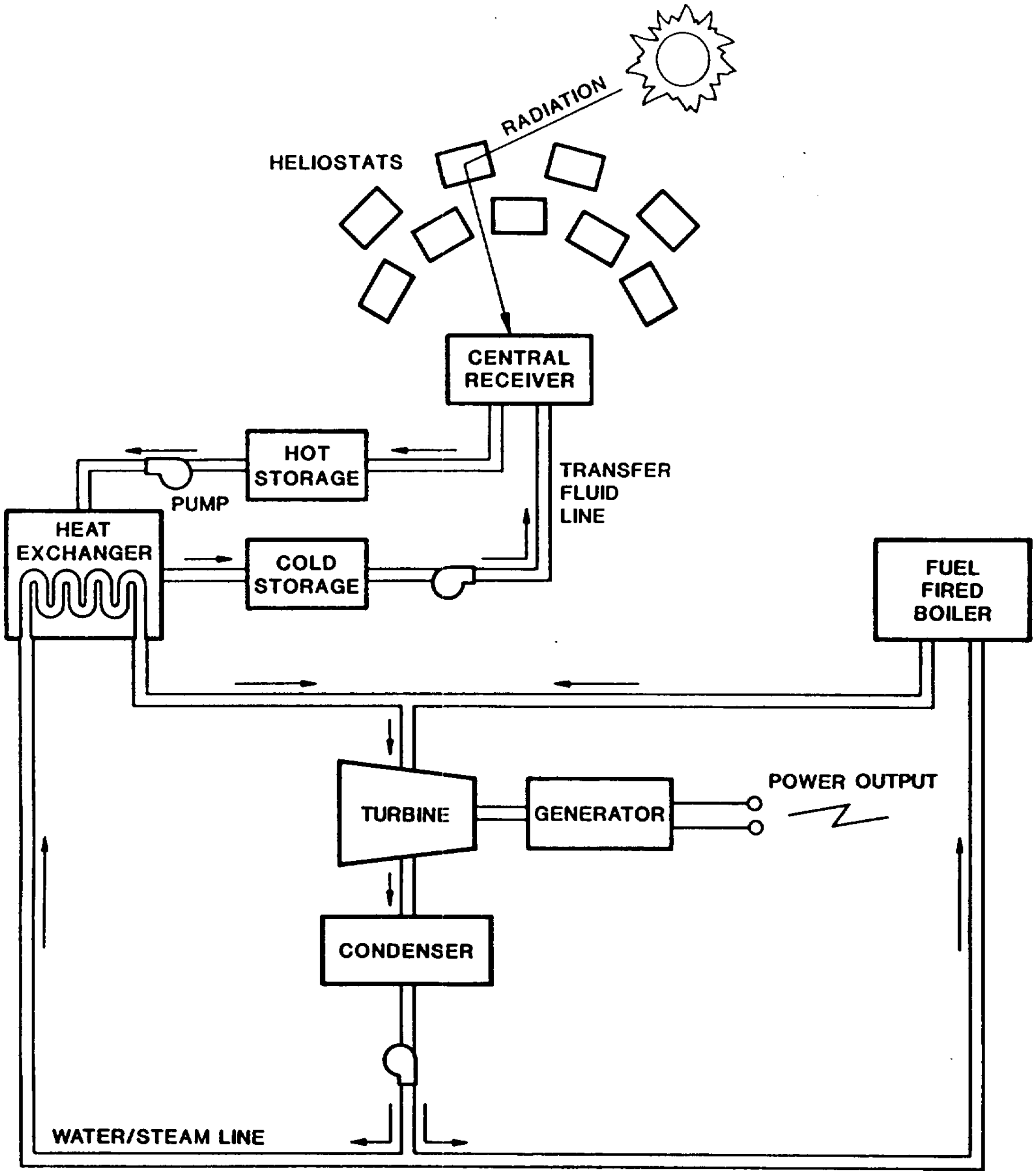
a. Three types of central plant configurations are generally recognized: central receiver systems, distributed collector systems, and solar ponds.

(1) In a central receiver system, the sun's rays are concentrated by an array of mirrors onto a central collector. The central collector is customarily located on top of a tower (see figure 9). The mirrors, called heliostats, are controlled individually by microprocessors to maintain correct orientation with the sun. Maximum solar energy is received and reflected by the heliostats when the angle subtended by the sun's rays and the plane of the mirror is near 90 degrees. The concentrated solar energy is converted to high levels of heat at the collector. This heat, in turn, is used to produce steam which drives the turbogenerators.

(2) A distributed collector system employs a number of concentrating collectors which are connected to a network of pipes containing a high-heat transfer fluid, as shown on figure 10. Focusing lenses or parabolic reflectors are used to concentrate the sun's rays directly onto the individual collectors. The fluid, which is heated in the collectors, is pumped through the piping network to a heat exchanger, where water is converted to steam to drive the generators. A major disadvantage of a large distributed collector configuration is the network of piping, which is exPenslve to install and maintain.

(3) A solar pond, which is shown on figure 11, uses a concentrated brine layer at the bottom of a shallow pond to collect and store the heat of solar radiation. The depth of a solar pond usually ranges from one to three meters (from 3.3 to 10ft). The pond bottom has a dark color to maximize solar radiation collection. Brine solutions are used so that the lower levels have a higher density than the upper levels. The heat gradient, which would naturally increase toward the pool surface, is reversed. Fresh water may be pumped over the upper levels to provide a cooler surface and some type of transparent cover may be added to reduce evaporation. As shown on figure 11, the heated brine is passed through a boiler to drive the turbine and generator. The steam-producing water can also be piped through the lower levels of the pool to absorb the heat through heat exchanger action. Temperatures in a solar pool may reach 100 °C (212 °F). Solar ponds are ideal for use in geographical areas that contain salt lakes.

b. Solar-powered heat engines can be used to meet the power demands of small installations. These devices convert solar energy, in the form of heat, to mechanical energy. This mechanical energy can then be converted to electrical energy. Solar-powered Sterling engines operate by means of a cycle involving the heating of a working gas (hydrogen or helium) and piston action, similar to that of the internal combustion engine. A major difference is that these solar-powered engines use heat from the sun, which is passed through the cylinder walls, rather than from the internal burning of hydrocarbon fuel. Several types of fuels can be used to provide the external heat source of a Sterling engine.



CENTRAL RECEIVER SYSTEM

FIGURE ILLUSTRATES HOW A SOLAR THERMAL ENERGY CONVERSION MIGHT BE USED WITH A CONVENTIONAL FUEL FIRED BOILER SYSTEM TO PROVIDE CONTINUOUS, ECONOMICAL ELECTRICAL POWER

FIGURE 9. Central receiver solar system.

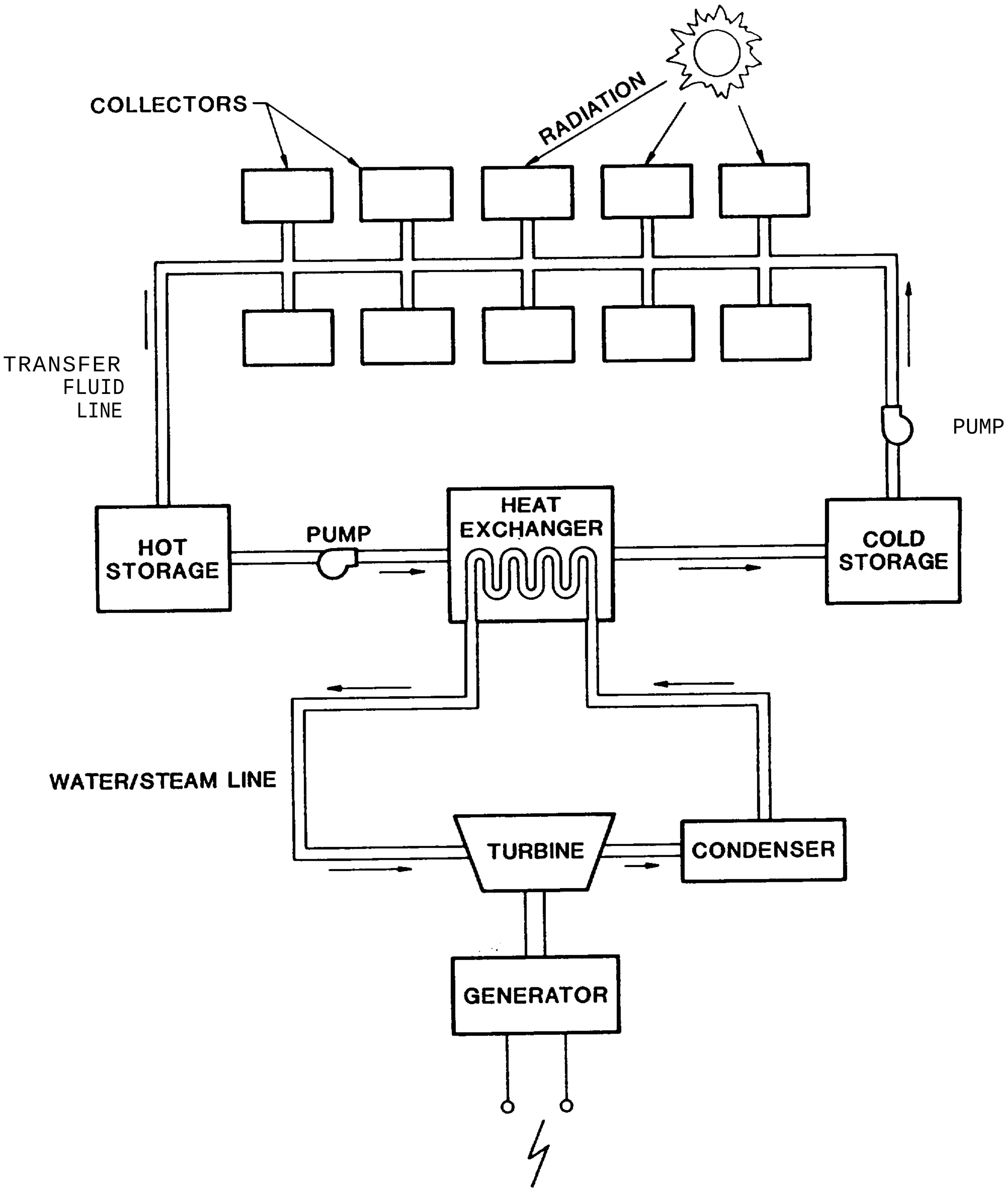


FIGURE 10. Distributed collector solar system.

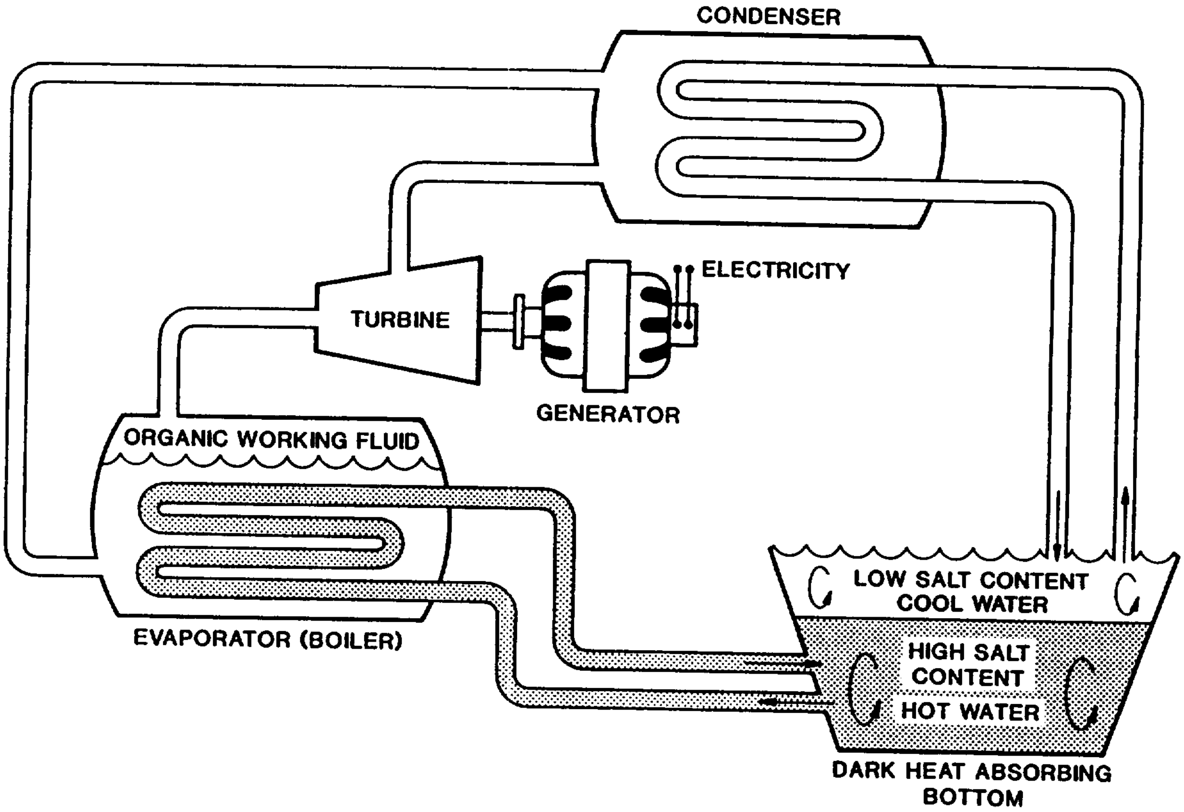


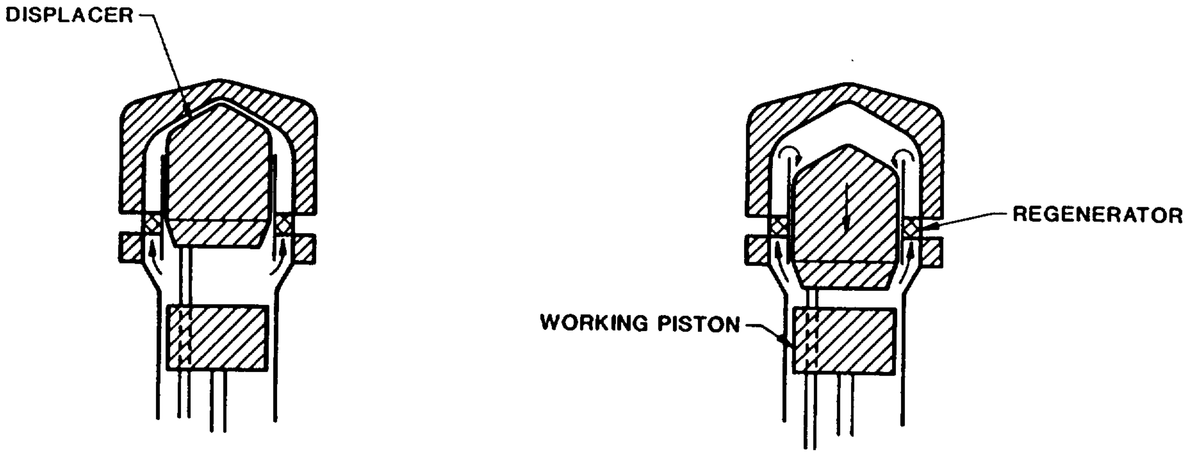
FIGURE 11. Solar pond.

(1) The Sterling engine uses a four-step cycle, as shown on figure 12. The cylinders have a second piston, called a displacer or transfer piston. The displacer transfers the working gas back and forth between upper and lower spaces. In the second step, gas in the cold space is compressed by the piston. In the second step, the displacer moves the compressed gas from the cold to the hot space. Next, the expanding, heated gas is transferred back to the cold space, moving both the piston and the displacer. The displacer is then moved to its upper position and the next cycle begins. During transfer between the hot and cold spaces, the working gas passes through an engine component called the generator. Heat from the expanding gas is retained in the regenerator. When the compressed gas is moved back to the hot space, it absorbs this stored heat. The Sterling cycle is complicated and requires precise timing.

(2) An innovative application of the Sterling-cycle engine is being used with solar energy. Rather than employing mechanical linkage to generate electrical power, engine parts also perform alternator functions. In a free-piston Sterling engine, the piston acts as the moving component in a fixed magnetic field producing an alternating current. By proper design, a piston oscillating 60 times per second produces 60-Hz current. Free-piston devices are commonly mounted at the focus of a parabolic solar collector, as shown on figure 13.

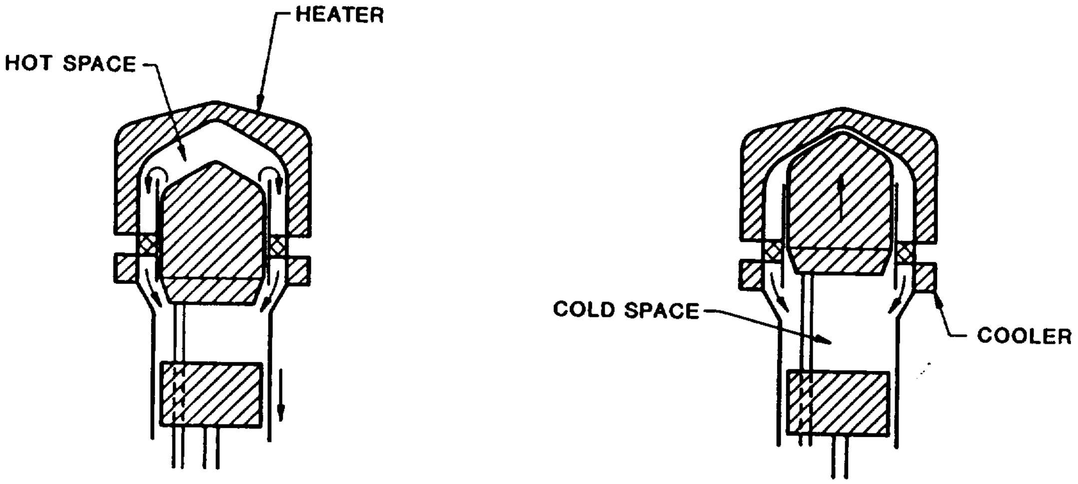
(3) Because of regenerator action, Sterling engines are inherently efficient, requiring relatively small solar reflectors. They must be carefully loaded to ensure continued efficiency through proper operation. These quiet running engines, with few moving parts, require minimum servicing and have demonstrated long lifetimes (mean-time-between-fail ures (MTBF) of 10,000 hours). Accordingly, the employment of Sterling engines at small, remote locations and in mobile operations is desirable.

5.2.10.2 Renewable alternate fuels. A variety of renewable gas, oil, and alcohol-type fuels are being developed by biomass conversion. The U.S. Department of Energy (DoE) defines “biomass” as standing vegetation, aquatic crops, forestry and agricultural residues, and animal wastes. The photosynthesis process produces biomass when green plants convert solar energy, carbon dioxide, and water into carbohydrates. The DoE is sponsoring research into the practical production of fast growing trees, sugar crops (beets and cane), and other promising herbaceous plants. Byproducts from the agricultural and forestry industries are also sources of biomass. processes are used to extract the energy from biomass, either as a fuel product or directly as heat. Table IV provides examples of biomass conversion methods currently under study.



1. COMPRESSION OF WORKING GAS IN COLD SPACE

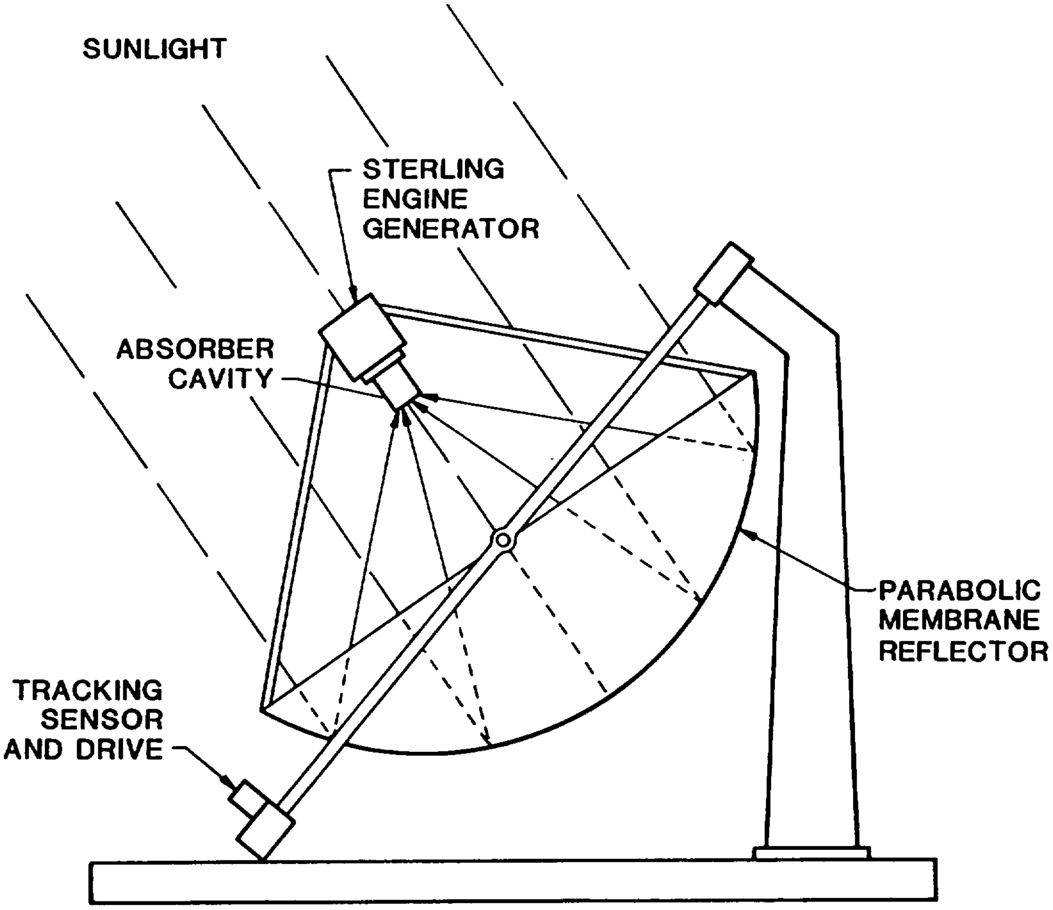
2. TRANSFER WORKING GAS TO HOT SPACE



3. TRANSFER WORKING GAS TO COLD SPACE, MOVING PISTON

4. DISPLACER MOVED TO UPPER POSITION

FIGURE 12. The Sterling engine cycle.



STERLING ENGINE GENERATOR MOUNTED AT THE FOCUS
OF A PARABOLIC SOLAR COLLECTOR

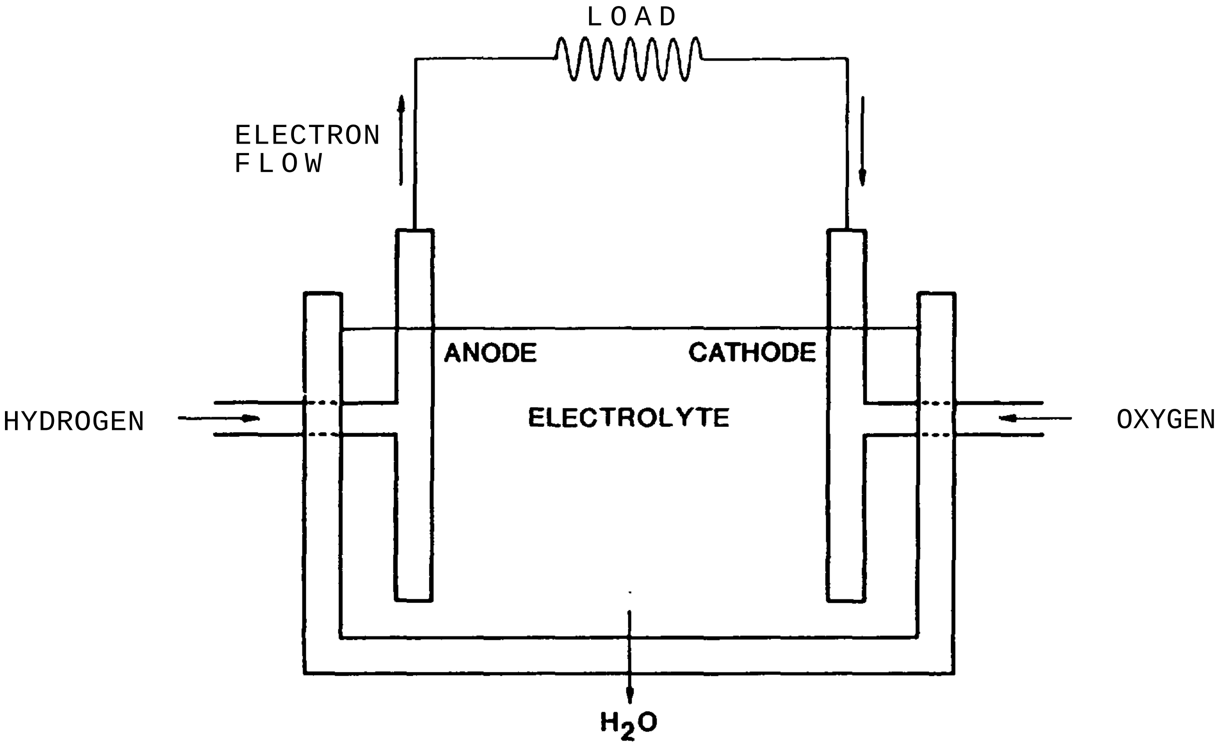
FIGURE 13. Sterling engine generator mounted at the focus of a parabollc solar collector.

TABLE IV. Biomass conversion methods.

PRODUCT	SOURCE	PROCESS
Methanol	Wood waste	Distillation
Methanol (from methane gas)	Organic refuse	Anaerobic digestion
Ethanol	Sugar crops (sugar beets, sugar cane, molasses) Starch crops (grains, tubers, root crops)	Fermentation
Ethanol	Cellulose (wood waste and plant stalks)	Acid hydrolysis
Methane	Manure, urban refuse (sewage and solid waste), agricultural refuse, aquatic energy crops (algae, kelp, water hyacinths)	Anaerobic digestion

5.2.10.3 Fuel cells. Fuel cells provide electrical power by converting the chemical energy released in the oxidation of hydrocarbon fuels directly into electrical energy. The chemical reaction involves the release of electrons that can be channeled as current through an electrical load. Fuel cells, which consist of two electrodes separated by an electrolyte, are actually types of primary batteries in which reactants are consumed. But, unlike what occurs in common primary battery cells, the electrodes and electrolyte of fuel cells are not consumed during the chemical process and the reactants can be fed from an external source. The most prevalent and successful fuel cell applications employ hydrogen and oxygen as the reactants that release electrons during the chemical (nonexplosive) reaction of producing water. Figure 14 illustrates the basic operation of a hydrogen and oxygen fuel cell. Note that the water by product of the fuel cell operation must be kept from contaminating or diluting the electrolyte.

a. Fuel cells are classified according to the type of electrolyte (liquid or nonliquid) they contain, temperature range (high or low) in which they operate, and the type of fuel they consume. Liquid electrolytes may be acid or alkaline, such as potassium hydroxide. Nonliquid electrolytes are in the form of alkali metal compounds. Operating temperatures between 70 °C and 200 °C (158 °F and 392 °F) are classified as low range. High temperature fuel cells have an operating range of 600 °C to 800 °C (1110 °F to 1470 °F). Low



AT THE ANODE, HYDROGEN (H) REACTS WITH THE HYDROXYL IONS (OH) OF THE ELECTROLYTE TO FORM WATER AND RELEASE FREE ELECTRONS (E) IN THE FOLLOWING REACTION:

$$H_2 + 2OH^- \longrightarrow 2H_2O + 2E$$

AT THE CATHODE, OXYGEN (0) REACTS WITH WATER AND FREE ELECTRONS (E) TO FORM HYDROXYL IONS IN THE FOLLOWING REACTION:

FIGURE 14. Hydrogen/oxygen fuel cell.

temperature cells require a catalyst to stimulate the chemical reaction, while high temperature cells generally do not. Fuel may be introduced into the cell directly as pure hydrogen and oxygen or indirectly involving some type of fuel processing of hydrogen- and oxygen-rich materials external to the cell.

b. The application of fuel cells in tactical and mobile operations is receiving much study. Fuel cells also can be used in fixed communications and data processing installations as replacements for engine-driven power plants. They have the advantages over engine-driven generators and conventional batteries of being lighter in weight, smaller in size, less polluting, and essentially noiseless. The disadvantages of current fuel cell technology are costs and lifetime (typically 6000 hours). As technology advances, the efficiency, reliability, and lifetime of fuel cells will improve, making them increasingly attractive for supplying power to electronic loads. Table V provides examples of fuel cell development for C-E application.

5.2.10.4 Wind energy conversion. The power of the wind has been used throughout history to move shim, pump water, and grind grain. Making electricity with wind-powered turbine generators had its beginnings in Europe about 1910. Interest in electricity through wind energy conversion was limited until recent times, because cost considerations have made the use of fossil fuels more attractive. The energy crisis of the 1970s, and the potential for energy tax credits, greatly revitalized interest during the 1980s. The major shortcoming of the use of wind energy is, of course, its intermittent character. Also, large wind turbine installations are still relatively expensive. The use of renewable wind energy as a supplemental source of electrical power should be considered in those geographical areas where site survey data indicate high availability of winds. Similarly, composite power plants using wind turbines along with other solar energy applications (solar cell arrays) and storage batteries can provide clean, economical electrical power. The advantages of wind energy conversion applications at small remote locations are obvious.

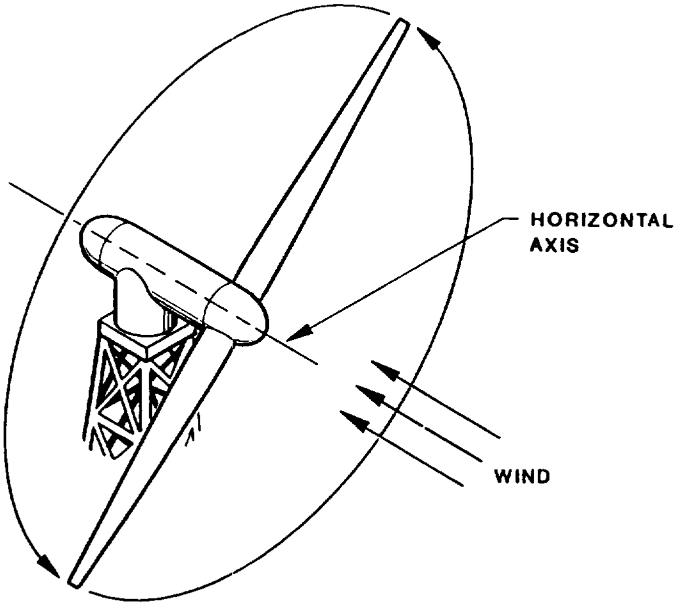
a. The basic principle of wind energy conversion is simple. Moving air has kinetic energy due to its mass and velocity. This kinetic energy moves some types of blades and rotors that are mechanically connected to a turbine generator shaft. A variety of blade and rotor shapes, mounted on horizontal or vertical axes, use aerodynamic lift or drag for movement. Examples are shown on figure 15. Drag devices, more commonly of the vertical-axis type, operate inherently at lower speeds and require gearing to drive generators at appropriate speeds. Vertical-axis devices function with the wind blowing from any direction. Horizontal-axis devices must be oriented with the direction of wind flow. The amount of wind energy (Pw), expressed in W/m^2, that is theoretically available at any instant for conversion to electricity by a wind turbine is a function of the air density (p), wind velocity (V), and effective cross-sectional area (A) swept by the blades or rotors. This functional relationship is expressed by the following formula:

$$P_w = (1/2)\rho AV^3$$

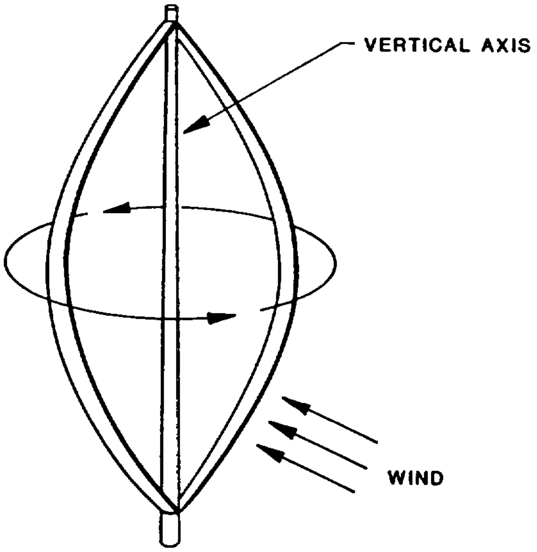
TABLE V. Fuel cell development C-E applications.

FUEL CELL TYPE	RAW FUEL	CATALYST	RAM (hours)	POWER	VOLUME	WEIGHT	PROJECTED LIFETIME (hrs)
Methanol	58 percent methanol- 42 percent water mix	Platinum-catalyzed nickel (alkaline electrolyte)	500 MTBF 6.0 MTTR	1.5 kW 3 kW 5 kW	0.158 m^3(5.6 ft^3)* 0.26 m^3(9.4 ft^3)* 0.36 m^3(12.8 ft^3)*	99 kg(220 lb)* 135 kg(300 lb)* 225 kg(500 lb)*	6000 6000 6000
Hydrocarbon	Liquid and gaseous hydrocarbons	Palladium silver	500 MTBF 6.0 MTTR	1.5 kW 3 kW 5 kW	0.198 m^3(7.0 ft^3)* 0.305 m^3(10.8 ft^3)* 0.427 m^3(15.1 ft^3)*	81 kg(180 lb)* 162 kg(360 lb)* 270 kg(600 lb)*	6000 6000 6000
Hydrazine 650+	Hydrazine (N H)	None		60/240 W	0.0042 m^3(259 in^3)	12.6 kg(28 lb) 8.5 kg(19 lb)	
		(hydrazine directly oxidized		300 W 1.5 kW	0.0127 m^3(.45 ft^3) 0.476 m^3(168 ft^3)	117.0 kg(257.4 lb) 6.75 kg(15 lb)	 10,000
Solid polymer ectrolyte (SPE)	metal hydrides alkali earth metals	None		30 W	943.9 cm^3(576 in^3)		

RAM - Reliability, availability, maintainability.
MTBF - Mean-time-between-failures.
MTTR - Mean-time-to-repair.
* As specified in the required operational capability (ROC).



HORIZONTAL AXIS TYPE



VERTICAL AXIS TYPE

FIGURE 15. Wind energy conversion devices.

b. In actual operation, energy losses reduce the efficiency of wind turbines to a maximum of about 40 percent. Air must pass through the plane of the blades or rotors in order for a wind turbine to function (rotate). During fluctuations in wind velocity, especially when increasing from a near-zero state, the inertia of the air causes delays and the use of some wind energy is lost. Other losses are attributed to the mechanical and electrical conversion processes. Detailed information on wind turbines can be found in military department manuals.

5.2.10.5 Small nuclear reactors. Major concerns over the use of nuclear reactors have been: high initial costs, personnel safety, and protection of the environment. Most research efforts to develop small nuclear reactors have been for space applications. With a power production capability from a few hundred watts to several kilowatts, small nuclear reactors are attractive for use at lower power electronic facilities in remote locations. Despite their potential hazards to personnel and the environment, the clean and quiet operation and long life of nuclear reactors can be seen as advantages, particularly in tactical environments. The technical aspects of nuclear reactors are beyond the scope of this handbook. Very simply stated, energy released by the nuclear fuel is used to heat a thermoelectric material or a medium (steam or gas) that drives a turbine generator. Costs per kilowatt are high, but may be overcome by continuous use and a long lifetime. When research-and-development efforts produce practical models, small nuclear reactors will likely find application at selected DoD facilities.

5.2.11 Life safety. Life safety has two components -- those protective measures necessary to prevent electrical injury and death, and sensing and warning systems such as fire detection and hazardous gas detection (in battery rooms).

5.3 Systems engineering. The design of each component of the power system should include:

a. Simplicity.

b. Reliability.

c. Flexibility.

d. Operability.

e. Maintainability

f. Quality.

g. Cost effect

5.3.1 Simplicity. Simplicity is the concept of design that makes the philosophy and theory of the design obvious to the least-trained person involved in the operation. Because of the potentially lethal nature of electricity, and the consequences of improper operation, the design must be simple.

5.3.2 Reliability. Reliability is the concept of design that instills confidence that a system will function without worry of failure. While maximum reliability comes at a price, reasonable reliability can be ensured by using proven quality components, and by adequate sizing to support immediate and future requirements.

5.3.3 Flexibility. Flexibility is the concept of design which recognizes that mission change. The design must include a provision for growth and reconfiguration that does not adversely affect the operation during the retrofit.

5.3.4. Operability. Operability is an adjunct to simplicity. Avoid designs that require special training and are labor intensive in day-to-day operation.

5.3.5 Maintainability. Power system maintainability has two major parts - the capability to bypass (or isolate) the failure, and rapid repair or replacement of the failed element.

5.3.6 Quality. Quality design of the power system ensures that the power delivered to loads is free from power abnormalities. These abnormalities can cause loss of synchronization, discontinuity of the switching function, or physical damage to the electronic equipment. The primary method of accomplishing this is to separate those loads which inherently produce transients from those which are susceptible to malfunction from poor power quality.

5.3.7 Cost effectiveness. Cost effectiveness is the most difficult component to include in the design. The use of low-cost components does not ensure reliable cost-effective power. A careful balance between the exact requirements of the system and the cost of the components leads to cost effectiveness. Further, the designer should consider the life-cycle of each component in the design.

5.4 Power generation. Although direct current is used extensively to locally power DoD communications and computer equipment, the generation and distribution of power is primarily concerned with alternating current. A minimum power-generation system consists of an energy source, a prime mover, a generator, a control system, and a load. One of the main reasons for use of ac is the ease of stepping voltages up and down to match load requirements. In addition, ac lends itself to generation and transmission as three distinct phases separated by 120 degrees. This phase arrangement makes generators more efficient and permits motors to start and run smoother.

5.4.1 General. There are a considerable number of voltage and phase arrangements used in DoD facilities to meet the demands of currently installed DoD electronics systems. Facilities required to use host country power that has a nonstandard frequency and voltage must be specially engineered to meet electronic equipment requirements. Where commerical power is used, the facility may also have an auxiliary power source. A short reveiw of ac power theory has been included at appendix A to this handbook. The operation of a small generator is described in the following information on ac generators. The discussion of dc power appears in 5.8.

5.4.2 Classes of power sources. Military electrical power systems are sometimes classified by the general functional requirements that they satisfy. Table VI is an example of how one military department identifies and defines the classes of power.

5.4.3 Generating unit. An ac power-generating unit converts mechanical energy to electrical energy. A generating unit is made up of three components:

a. A prime mover - normally a diesel engine with its controls and accessories.

b. An ac generator - composed of an exciter, alternator, and a voltage regulator.

c. A control system may have separate sections to regulate the operation of the prime mover, coordinate the operation of multiple generators, and distribute the generated power into the facility's power system.

5.4.3.1 Generator control systems. Discussions about ac generating units can become very complicated because it is possible to classify generating units based on the characteristics of their major components. For example, a generating unit may be classified according to the type of prime mover (e.g., a diesel generator) or according to the type of drive used to couple the prime mover and generator together (The most widely used coupling is the direct connection of the generator and prime mover drive shafts.) Generating units are also classified according to their phase arrangements. The most widely used generating units in DoD facilities are four-wire, three-phase units. In addition, a generator can also be classified based on the complexity of its control system. Generator control systems range from the simple manual start, manual power transfer to an elaborate automatic power-transfer system which has the following functions:

a. Continuously monitors the operation of the primary power source.

b. Senses a disturbance in the primary source (e.g., a power failure loss of phase, incorrect voltage, or frequency).

c. On sensing a disturbance, initiates a signal to start the auxiliary gerating unit s prime mover.

d. Transfers the critical load to the auxiliary generating unit when it senses the auxiliary generating unit's voltage and frequency are in proper range.

e. After restoration of the primary power source, transfers the critical lod back to the primary source.

f. Shuts down the auxiliary generator unit and resets itself to be ready to sense another failure of the primary power source.

TABLE VI. Classes of electrical power.

Power class	Operational power requirements.	Characteristics
Primary power, class A	Includes all utility technical, and critical operational loads	Subject to voltage and frequency deviations, transients, and occasional complete power failure
Auxiliary power, class B	Same as class A. Same as class A. Capable of extended operation. Automatic system operation at -10% or +10% voltage variation after 5-second delay. Covers extended outrages. that may last for days.	Supplement to primary power. Subject to complete loss of synchronized power for up to 20 seconds during automatic power transfer following primary power loss
Auxiliary power, class C	Provides autostart power plant for rapid restoration of power to the technical load. Starts on voltage variation of ±10% or on frequency-variation of ±3.3% with an adjustable time delay of approximately 5 seconds. Minimum fuel supply of 1 days covers outages of relatively short periods (hours)	Supplement to primary power. Ensures load in the shortest practicable time following failure of primary power (from 10 to 60 sec)
Uninterruptible power System and no break, class D	Provides continuous uninterruptible power and prevents the transmission of transients and surges to the critical technical load	Automatically assumes load when required, and automatically shifts load back when primary power becomes available. No power interruption and minimal voltage and frequency deviations

5.4.3.2 Automatic transfer switches. When a primary power interruption (or loss of phase) is detected, automatic transfer switches start an emergency power source and then transfer their load circuits to the auxiliary power. When the normal supply is restored and is stable, the transfer switches automatically retransfer their load circuits to the normal supply. Figure 16 illustrates the use of an automatic transfer switch to provide emergency power. To avoid extended downtime during maintenance or repairs, all automatic transfer switches serving critical loads should have a manual bypass included in the original design. Phase monitoring on the load side of the supplied power, using specifically-designed monitoring equipment, is essential to ensure that phase discrepancies are detected and recorded.

5.4.4 Prime mover. Although it is more costly and heavier in smaller sizes, the diesel engine has almost completely replaced the gasoline engine as a prime mover. Diesel fuel has advantages over gasoline since it usually costs less, and fire and explosion hazards are considerably lower than gasoline. A prime mover is an electric generating unit that produces mechanical energy and delivers it to the generator for conversion into electrical energy. The best prime mover is one that delivers rotary power and has sufficient capacity, reliability, and economy to meet the requirements for the attached generator.

5.4.4.1 Air intake system. Because the power developed by a diesel engine depends largely upon the proper burning of fuel, plenty of clean, fresh air must be available. Normally, atmospheric pressure supplies air to the engine. However, when the pressure is insufficient, mechanical blowers must pressurize the air to increase engine horsepower, especially at high altitudes. All diesel air intake systems have filters that remove dirt and dust from the air as it enters the system.

> NOTE: At elevations above 1000 m (3300 ft) and where intake air temperatures exceed 40 °C (104 °F) deration specifications provided by the manufacturer must be considerations. These output derations typically range from 2 to 5 percent per 305 m (1000 ft) for altitudes above 1000 m (3300 ft) and from 1 to 3 percent per 5.5 °C (10 °F) above 4U °C (104 °F).

5.4.4.2 Exhaust system. It is advisable to run the diesel exhaust through the side of the building see figure 17). This reduces the chance of roof leakage caused by vibration. This option is not without penalty, as the losses of each exhaust system element (elbows, silencer, flexible, and straight pipe sections) must be added to determine total exhaust system back

5.4.4.3 Diesel engine fuel system. The functions of the diesel engine fuel system are to: (1) carry the fuel from the fuel storage tanks, (2) measure out or meter the fuel into charges sufficient for one power stroke, and (3) force each charge into a combustion chamber at the proper time, under high pressure. Diesel fuel is injected into the compressed air of the combustion

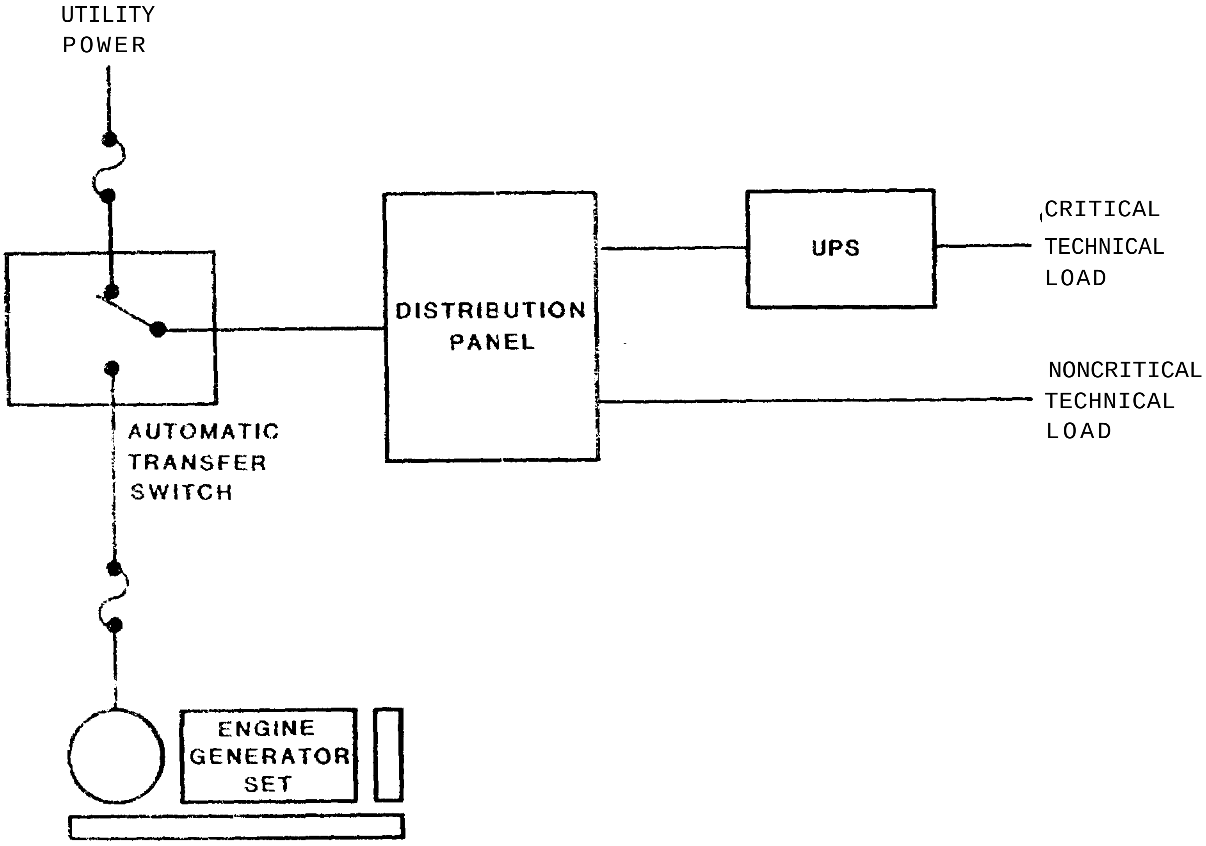


FIGURE 16. Emergency generator transfer switch.

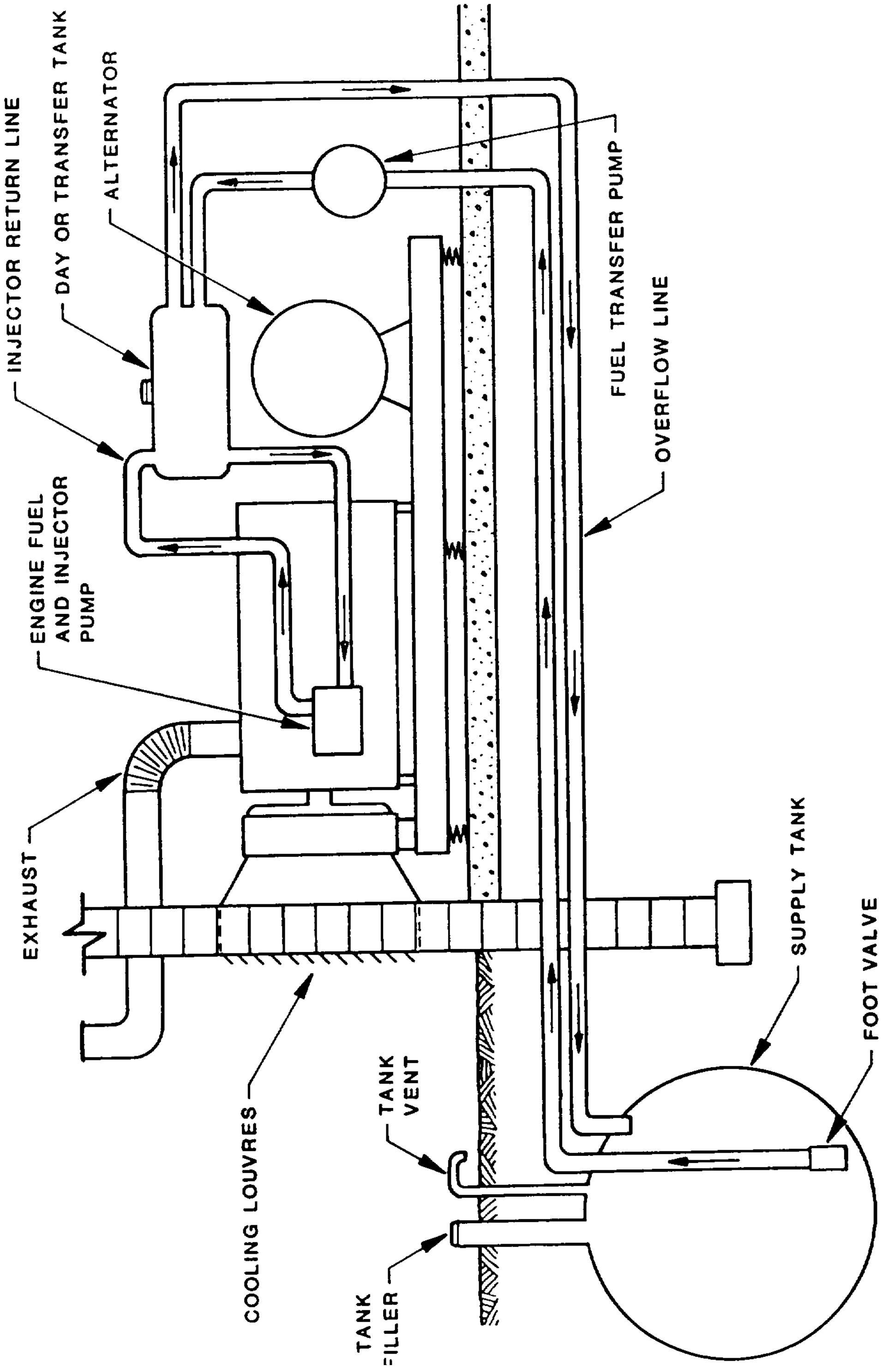


FIGURE 17. Diesel fuel system.

chamber that is hot enough to ignite the mixture. Figure 17 shows a diagram of a typical diesel engine fuel system. The fuel is drawn from the storage tank, strained and filtered, and delivered to the fuel injection system. A transfer, or day tank, is normally used adjacent to the engine to ensure starting in the minimum possible time. These 5-to-25 gallon tanks contain room temperature fuel and ease the starting task of the fuel transfer pump.

5.4.4.4 Fuel selection and storage. Gaseous fuels are seldom used for emergency generators.

> NOTE: If, for some reason, they are selected, natural gas must not be used as a primary fuel for DoD systems because it is considered an interruptible supply.

Galvanized pipe, fittings, or tanks are not to be used with diesel fuel systems due to the reaction of the fuel with the coating. The chemical reaction causes the coating to peel and damages fuel injection systems. A remote fuel-tank-level indicator should be installed when a new facility is built, or when an existing tark is replaced. At all new underground tank installations, a tank leak detection system must be installed. National codes on tank location and coristruction include NFPA 30, Flammable and Combustible Liquids Code, and NFPA 37, Stationary Combustion Engines and Gas Turbines.

5.4.4.5 Cooling system. The cooling system of internal combustion engines keeps the cylinder walls and head from overheating. Two general types of cooling systems are used - air and liquid. The air-cooling system depends upon the flow of air past the cylinder walls and the head to carry away the excess heat. Air cooling is seldom used on generator engines greater than five horsepower or on multicylinder engines. When air-cooled engines are operated indoors, there must be an adequate supply of fresh air. A liquid-cooling system depends upon a liquid coolant to absorb the heat from the combustion walls and carry it away from the engine. Heat is extracted from the coolant by a radiator, an evaporative cooler, or other types of heat exchangers. The liquid-cooling system is used on a wide range of engines, since it can handle large amounts of heat rapidly.

5.4.4.5.1 Radiator. A radiator is used on most portable, liquid-cooled generators. The radiator has an upper tank and a lower tank. Between these tanks a large number of small, thin-walled tubes carry the coolant flow. The amount of coolant passing through the radiator is controlled by a thermostat and bypass valve so that the engine temperature is maintained at a nearly constant level. Since air must carry away the waste heat from the radiator, engine room temperature is raised. Provisions must be made to exhaust the heated air. (Refer to figure 17). Where it is possible, the radiator should be located in a separate room from the generating unit.

> NOTE: If the remote radiator is cooled by an electric motor-driven fan, the motor and motor-start solenoid must be protected from larqe transients, such as those generated by lighting and EMP.

5.4.4.5.2 Evaporative cooler. In warm, dry climates, an evaporative cooler (cooling tower) can be used on large engines where the heat is so great that transfer from the coolant to the air becomes difficult. For some cases, heat for the power plant building (heat recovery) may be obtained from the engine coolant. The heating requirements of the building should be computed and compared with the heat available from the engine. If the balance is favorable, heating coils may be installed and the coolant pumped through them. The theory of evaporative coolers is discussed in volume III of this handbook,

5.4.4.6 Engine lubrication. The lubricating system is of the utmost importance, because a failure of the lubricating system will cause engine damage. The functions of lubricating oil in an engine are to: reduce friction between moving parts, cool engine parts, clean the engine components, prevent corrosion of the engine surfaces, and act as a compression seal between the piston rings and cylinder walls. The diesel engine lubricating system must circulate, filter, and cool large quantities of lubricating oil. A pump is needed to circulate the lubricating oil through the engine lubricating system. Oil pump capacities vary with different engines and range between two and five gallons per kid-rated output per hour.

5.4.4.7 Preheater assemblies. Various types of preheater are used on diesel enqines to help start them when the temperature is low. The purpose of the prheater assemblies is to keep the engines at operating temperatures all the time, so they can be easily started and brought up to full power almost instantly. Electric preheater consist of an electric filament placed in either the lubrication system or the cooling system of the diesel engine. The filament is heated by electric current from the starting batteries or by commercial power.

5.4.4.8 Engine governors. A governor automatically varies the flow of fuel to the engine, so that the power developed equals the power required at the desired engine speed. Maintaining developed power is directly related to output frequency stability. An isochronous governor maintains constant engine speed from no load to full load with typical accuracies of ±0.25 percent of rated speed. Mechanical governors sometimes used on smaller (below 150 kW) units are capable of regulating the no-load to full-load frequency within 5 percent of rated value, and ±0.5 percent error during steady-state operation.

5.4.4.9 Alarm and shutdown systems. An alarm or shutdown control device that responds to abnormal operating conditions, such as temperature, pressure, or engine speed protects the engine. Temperature sensing devices are important indicators in engine operation. They sense the temperature of the oil, water, fuel and intake air, or exhaust gases. Most modern engine-generator sets are equipped for automatic plant shutdown when operating parameters are exceeded. NFPA-76A requires individual alarm lights for the conditions as shown at table VII.

TABLE VII. NFPA-76A alarm light recommendations for engine generators.

Low engine cool art temperature (heater not functioning)
High engine temperature prealarm (approaching shutdown)
Unit shutdown due to high engine temperature
Low oil pressure prealarm (approaching shutdown)
Unit shutdown due to low oil pressure
Unit shutdown due to overcrank (engine fails to start)
Unit shutdown due to overspeed (line frequency rise)
Indication that emergency source is supplying load
Indication of batter charger malfunction
Indication of low fuel in main tank

5.4.5.1 Brush-type ac generator. In the brush-type generator, the exciter generally is housed in a separate housing from the alternator. The distinguishing characteristic of a brush-type generator is that the brushes are used to transfer the exciting current to the alternator's rotors. Brush-type alternators consist of three major assemblies. These assemblies are: the rotor (shaft assembly), the stator (frame assembly), and the collector (collector slip rings, brushes, and brush holders). As the dc flows from the exciter to the-alternator; it flows through the brush and slip ring of the collectors to the alternator field coils in the motor. return path is through the collector's brush and slip ring back to the exciter. The direct current flowing through the motor creates a very strong electromagnetic field of alternating polarity. When the rotating electromagnetic field of alternating polarity passes in close proximity to the stator warnings, alternating current is induced into the stator windings. The stator in a four-wire, three-phase alternator has three sets of armature coils that are spaced 120 electrical degrees apart. On end of each coil is connected to a common terminal, the neutral. The other end of each coil is connected to separate terminals. Conductors attached to the four terminals carry the current to the generating switchgear and to the load. See appendix A for a review of generator theory.

5.4.5.1 Brush-type ac generator. In the brush-type generator, the exciter generally is housed In a separate housing from the alternator. The distinguishing characteristic of a brush-type generator is that the brushes are used to transfer the exciting current to the alternator's rotors. Brush-type alternators consist of three major assemblies. These assemblies are: the rotor (shaft assembly), the stator (frame assembly), and the collector (collector slip rings, brushes, and brush holders). As the dc flows from the exciter to the alternator, it flows through the brush and slip ring of the collectors to the alternator field coils in the motor. return path is through the collector's brush and slip ring back to the exciter. The direct current flowing through the motor creates a very strong electromagnetic field of alternating polarity. When the rotating electromagnetic field of alternating polarity passes in close proximity to the stator windings, alternating current is induced into the stator windings. The stator in a four-wire, three-phase alternator has three sets of armature coils that are spaced 120 electrical degrees apart. One end of each coil is connected to a common terminal, the neutral. The other end of each coil is connected to separate terminals. Conductors attached to the four terminals carry the current to the generating switchgear and to the load. See appendix A for a review of generator theory.

5.4.5.2 Brushless ac generator. Recently, significant improvements have been made in the design of ac generators. The need for exciter and alternator brushes has been eliminated with the application of silicon diodes or rectifiers. Brushes, commutators, and slip rings are a source of electrical noise and require considerable maintenance. The new brushless generating unit eliminates the brushes by combining the exciter and alternator rotating assembly on a common shaft that is coupled to the flywheel of the diesel engine. A common housing encloses the brushless generator components and supports the shaft on ball bearings. This unit uses the same type exciter as the brush unit. The only difference is in the alternator. The brushless alternator consists of: (1) the stator, the part containing the output windings, and (2) the rotor, which provides the magnetic field rotating within the stator. The exciter supplies dc power to energize the electromagnets of the alternator's rotor. The exciter stator contains the field winding, and the exciter rotor, on which the conductors are wound, rotates within the stator. The three-phase ac, which is induced in the exciter's rotor, flows in three leads to the rectifier assembly. The rotating rectifier assembly contains diodes and surge suppressors. The diodes form a three-phase, full-wave rectifier which resists wear, arcing, or contamination. During starting, a surge suppressor limits the initial voltage surge through the alternator field. Alternators require much less maintenance than their prime movers.

5.4.5.3 Voltage regulator. The voltage regulator varies the current to the exciter field to maintain a steady, alternator-output voltage under varying load conditions. A small part of the alternator's output goes to the voltage regulator, which meters dc back to the exciter's field windings. Normally, automatic regulators are used, although manually adjusted regulators are sometimes found at smaller Doll facilities. Voltage regulation is defined as the rise in output voltage (field current and speed constant) when the entire load is removed from the generator.

5.4.6 Automatic controls for auxiliary operating units. Many controls and accessories for use with auxiliary generating units have been developed. Controls intended for fully automatic starting systems should consist of:

a. A power monitor group which senses the quality of the power supplied to the load.

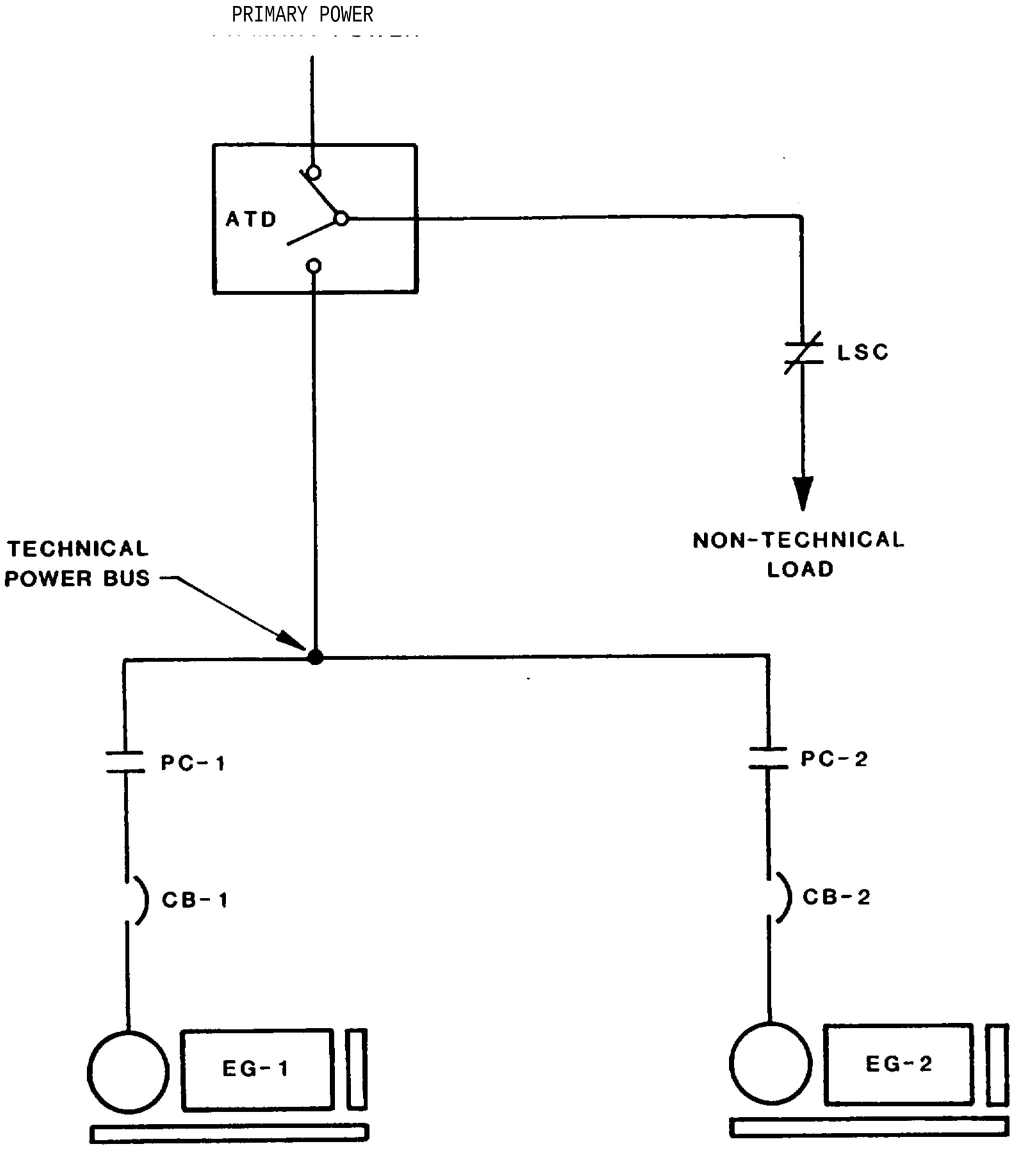
b. A generator control group which starts the auxiliary generating unit after it receives a signal from the power monitor.

c. A power transfer group which will shift the technical load from the normal source to the emergency source of power, and vice versa. Where the emergency power source is an automatically started, auxiliary, generating unit, automatic controls are equipped with either complete engine starting-and-stopping controls, or pilot devices to initiate engine starting through controls mounted on the engine.

5.4.6.1 Operation of controls. Generator controls are required to sense primary power status and provide alarms when generator or prime-mover operating parameters are abnormal. When the normal power source fails, the diesel engine starts. The transfer is made when the output voltage and frequency of the auxiliary generating unit are stable. After the normal primary-source voltage is restored, the load is transferred to the primary source and the auxiliary generating unit is shut down, either manually or automatically. A time-delay relay usually controls the automatic retransfer action by delaying until the primary power is stable. When the auxiliary power is not synchronized with the primary power, an interlocking breaker is required to prevent both power sources from operating at the same time. Also, the interlocking breaker can be used to keep the standby generator operating for a given time after the load has been transferred back to normal power. At this point, the generator control group resets itself for possible additional primary-source power failures. After the load has been transferred to the auxiliary generating unit, if the engine fails because of low oil pressure, overheating, or overspeeding, the generator control group will lock out the auxiliary unit, send a signal to the power monitor which actuates a remote alarm circuit, and switch the load to the primary power

5.4.7 Multiple generating units. Two or more generating units may be required to meet total facility power requirements. Multiple generating units also permit removal of a-unit from service to perform scheduled maintenance.

5.4.7.1 Parallel operation. Generating units to be paralleled must have the same frequency, the same number of phases, the same phase rotation, and when paralleling with a utility grid, the same voltage. The reason for parallel operation is that multiple units can supply power to the critical load with improved reliability, and still be used individually when smaller loads are required for peaking or load management. The capability to automatically synchronize generator sets with the utility feed permits delivery of continuous power to critical loads during scheduled commercial outages and makes cogeneration possible. Parallel operation can be achieved manually or automatically. Automatic operation is preferred, but a bypass to permit manual operation, in the event of a malfunction should be provided. Figure 18 depicts a system that causes both engines to automatically start following



LEGEND:

ATD	AUTOMATIC TRANSFER SWITCH
CB	CIRCUIT BREAKER
EG	ENGINE GENERATOR SET
LSC	LOAD SHEDDING CONTRACTOR
PC	PARALLELING CONTACTOR ELECTRICALLY OPERATED

FIGURE 18. Parallel operation of engine generator sets.

a utility power system failure. The first engine to reach operational voltage and frequency will actuate load shedding circuits and pick up the remaining load. When the second unit achieves synchronism, it is paralleled with the first. Then, depending on total generator capacity, all or part of the dumped load is reconnected.

5.4.7.2 Division of circuit loads. During the initial planning for installation of electronic systems, or when additional equipment is added, the primary load division must be considered. Indiscriminant loading of distribution power panels can result in:

a. Poor voltage regulation.

b. Circuit breakers dropping out when multiple equipment is used simultaneously.

c. Overheating of circuit breakers.

d. Ground loop problems. (When phases are unbalanced, neutral currents proportional to the unbalance will flow).

5.4.7.3 Generator connections. The output of modern generators is normally connected In a wye or star pattern rather than delta (see 5.6.5 of this volume). A delta-connected generator has only one recognized advantage over a wye-connected unit - on balanced loads that are primarily resistive in nature, the higher voltage-per-phase (typically 240 V versus 208 V) provides increased efficiency. The wye connection has the advantage of being able to bring out the neutral wire to handle momentary phase-current imbalances. It is difficult to design a delta-connected generator and keep circulating currents low. Normally, the wye-connected unit will produce better waveform characteristics than the delta-connected one. With a wye-connected generator, the harmonics tend to cancel each other. With the delta configuration, harmonic cancellation is only for the third harmonic and its multiples, which are cancelled by circulation in the windings.See table VIII for a summary of possible harmonics for the various generator connections. Delta-connected generators are used to supply 120/240-volt three-phase, four-wire systems, with the fourth wire acting as a grounding conductor. In DoD power systms, a fifth wire (green) is added to the wye distribution system for equipment protection.

> NOTE: Caution should be exercised when it is necessary to use a delta-connected generator for DoD facilities. Voltages from phase conductor-to-ground in a delta-connected system are typically much higher than with a wye-connected system.

TABLE VIII. Possible harmonics for different generator connections.

Connection	Grounded	Possible harmonics
Wye	Yes	1, 2, 5, 7, 9, 11, etc.
Wye	No	1, 5, 7, 11, etc.
Delta		3, 9, 15, 21, etc. (circulating) and 1, 5, 7, 9, etc. (line)

5.5 Power transmission. An example of a power transmission system required to connect remotely located ac generators to the customer site is shown on figure 19. Power is usually transmitted at several thousand volts from the generator location to the customer location. Transmission efficiency is achieved by using a higher voltage, because power loss is equal to the current squared times the resistance. By raising the voltage, the current is reduced, and for a fixed value of wire resistance, power losses are minimized. This arrangement also requires that a substation or transformer be located on or near the customer premises to reduce the voltage to the level required by the equipment load.

5.5.1 General. The following paragraphs include: suggested minimum electrical performance parameters for power transmitted to DoD power systems, the general requirements for a secondary distribution substation and the protective devices which may be used in the high-voltage section of the substation or in the facility, and switchgear commonly used.

5.5.2 Off-site commerical power. A site survey should determine the availability of commercial power transmission lines, and an evaluation should be made with regard to past reliability and availability factors. Using two widely separated commercial power lines may be preferred instead of one single line. This decision to use a second source should be made on a site-specific basis by the using Government agency.

5.5.2.1 Two commercial power sources. If two commercial power sources are used, the two commercial power substations should be located as far apart as practical, but reasonably close to the power plant for that DoD facility. Design guidance and guide specifications for the main substation can be found in individual service specifications.

5.5.2.2 Contract. The contract with any commercial power company should be based on single-point, primary metering. It should allow for the parallelincj of on-site generating units with the commercial power line(s) at

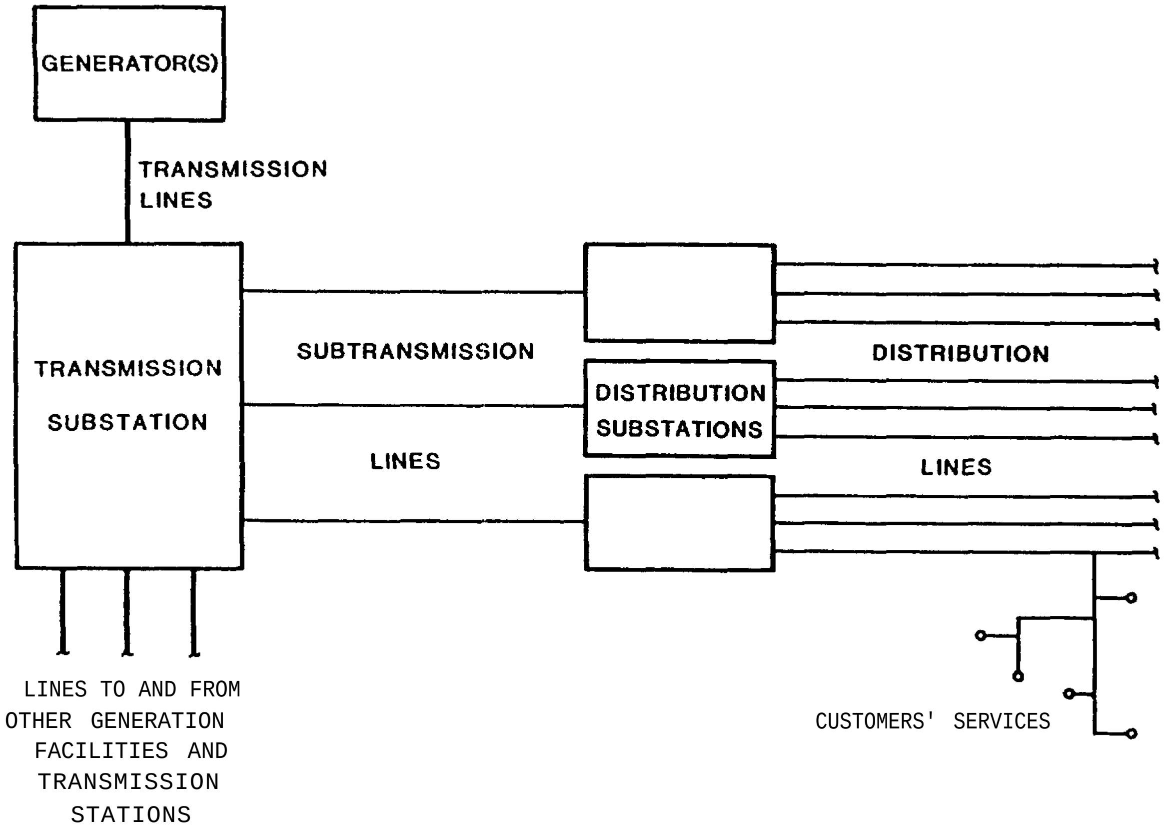


FIGURE 19. Transmission and distribution system block diagram.

the discretion of DoD facility user. The contract should require the company to maintain power at the site continuously, regardless of other power demands on the transmission system. The terms and conditions of construction, operation, and maintenance of the commercial power substation should be included in the contract. It is recommended that the contract require the power company to maintain the high voltage equipment (equal to or greater than 100 kV), but that the using DoD agency will procure and install all commercial power substation equipment, and operate and maintain the medium-voltage equipment (2.4 to 72.5 kV). Design approval should be obtained from the commercial power company, with appropriate safety measures applied by the commercial power company and the using DoD agency.

5.5.2.3 Commerical power sources. If two commercial power sources are used, the preferred arrangement for a double-ended substation is illustrated in figure 20.

5.5.2.4 Power factor correction. Power factor improvement or correction reduces the penalties charged by the utility company, and essentially increases the power system capacity. To avoid heavy penalties, most utilities insist that the power factor should be above 85 percent. capacity improvement is a result of reduced 1^2R losses and improved voltage levels. In smaller facilities, where the power factor varies due to load factors, adding suitable capacitors is the solution to improvement. Figure 21 illustrates a leading power factor where the current leads the voltage.

Power factor is the cosine of this angle or:

$$kVA = \frac{kW}{\cos} = \frac{kW}{PF}$$

Making the angle smaller between current and voltage decreases the kVA:

$$kVA\ reduction = \frac{kW}{PF_1} = \frac{kW}{PF_2}$$

PF_1 is before capacitance is added, and PF_2 is after capacitance is added. For a given kVA, raising the power factor will provide additional kW without adding components.

$$kW\ increase = (PF_2 - PF_1) \times kVA$$

Improvement of an electric motor power factor is accomplished by adding capacitors in the motor circuit as shown on figure 22. When it is not feasible to switch capacitors with motor loads, banks of capacitors may be added to appropriate locations in the power distribution system. Automatic power factor correction units are available to switch in capacitance, as required, to meet a certain power factor percentage. Small automatic power factor correction units are available to provide 0.99 power factor for office computers and peripherals. These units are also capable of reducing line harmonics to a level that will meet EMI-conducted noise limits. Consult motor manufacturers' specifications for capacitor placement. ANSI/IEEE Standard 241 discusses methods to control power factor levels.

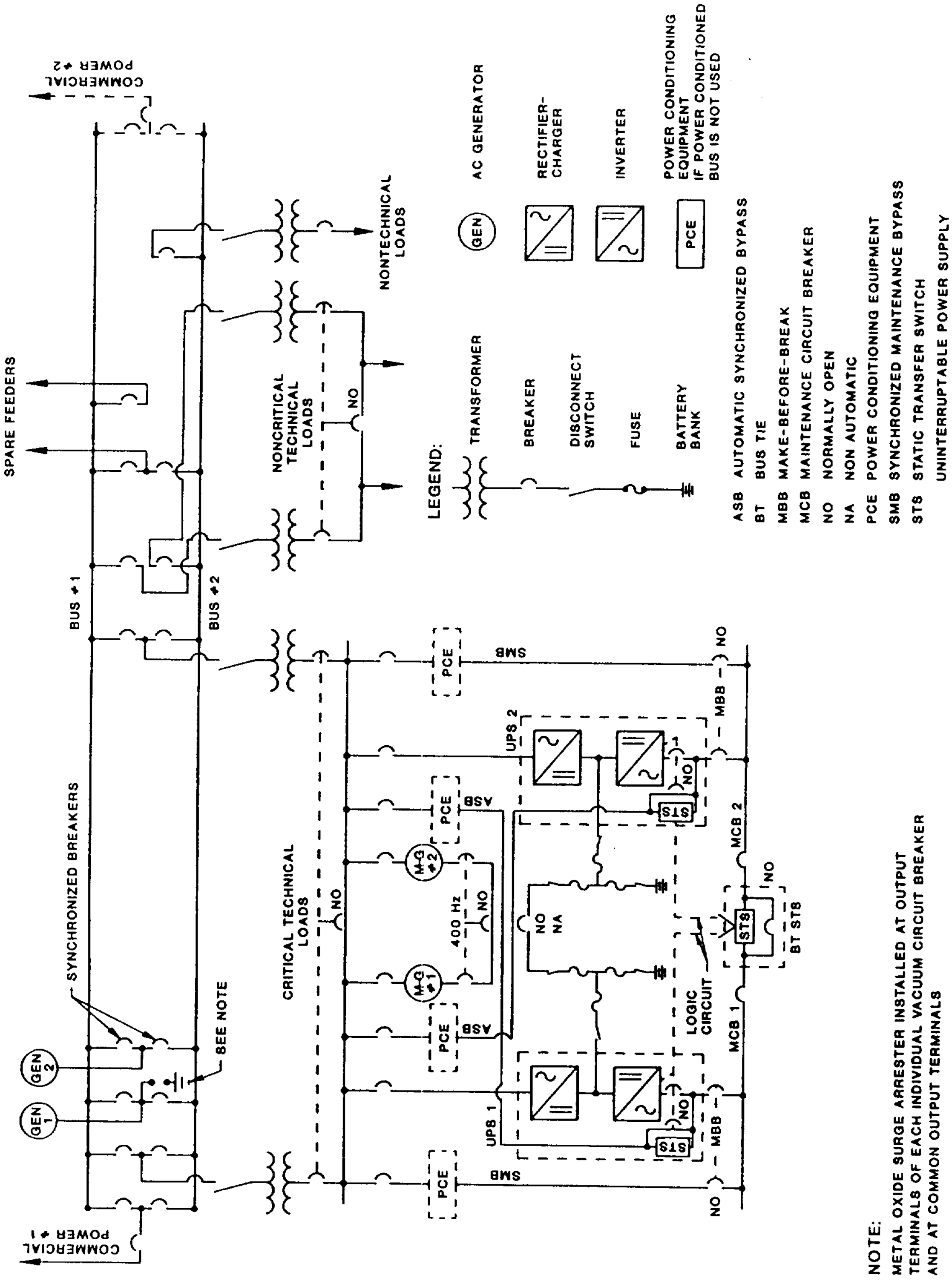


FIGURE 20. One-line diagram of a facility requiring all categories of power.

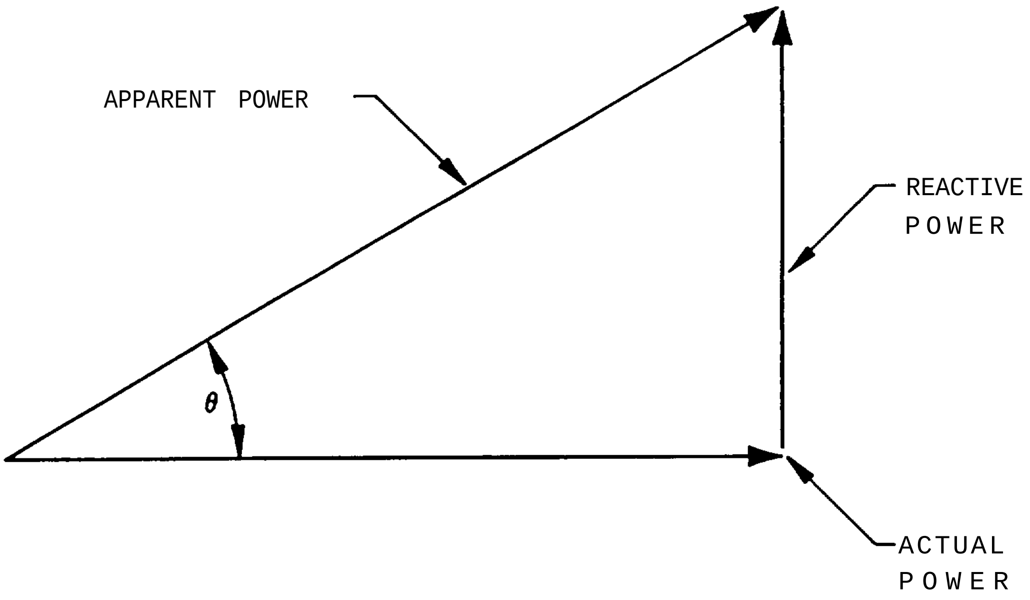
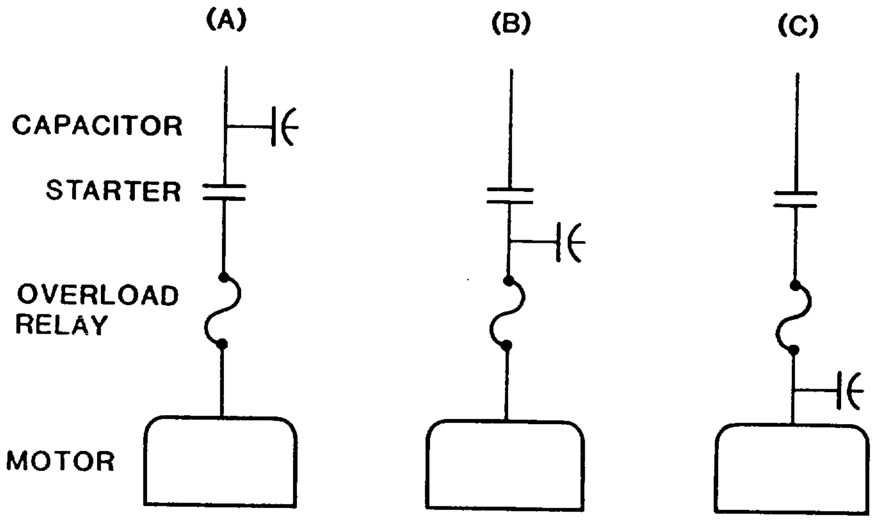


FIGURE 21. Leading power factor triangle.



CAPACITORS MAY BE ADDED (A) AHEAD OF STARTER CONTACTS, (B) AHEAD OF OVERLOAD RELAYS, OR (C) AT MOTOR TERMINALS

FIGURE 22. Electric motor power factor correction capacitor locations.

5.5.3 On-site power. For on-site power generation at a DoD communications facility, a power plant will use prime power (Class A - continuous duty) engine-generator units and associated ancillary and control systems. The number and sizes of engine generators will vary for different DoD sites. individual procurements, all engine generator sets and their auxiliaries in each power plant will be supplied by the same manufacturer.

5.5.4 Secondary distribution substation. The secondary distribution substation is usually the dividing point between the commercial and Government-owned transmission lines. In some cases, the commercial power company owns and maintains the substation; in others, it may be owned and maintained by the facility. In either case, the substation transforms the incoming power voltage to equipment utilization voltage.

5.5.4.1 Types of secondary distribution substations. Substations are classified by the method and location of their assembly. A secondary distribution substation may be constructed for indoor or outdoor application and should be located near the load utilization area. Most substation will be unattended, outdoor types. When attended by operators, the control, converting, and regulating equipment are placed within a building. The substation constructed at the site is the open-field assembled substation. The unit substation is one constructed in a single enclosure and is completely assembled by the manufacturer. The unit substation provides an excellent, economical method of transforming power voltages up to 13.8 kV down to the utilization voltages and should be considered for DoD facilities. All substations consist of three distinct sections: high voltage, transformer, and low voltage (less than 1 kV).

a. The high-voltage section is where the incoming line terminates and connects the incoming high voltage to the primary winding of the transformer. It also provides overcurrent protection for the transformer and a load disconnect switch. Lighting arrestors, which are connected to the incoming live terminals, may be supplied in the high-voltage section.

b. The transformer section converts the incoming voltage down to the utilization voltage (in most cases, 208/120 V or 480/277 V). Distribution transformers are usually wound with two coils for each phase, so the coils can be connected in series, or in parallel, to permit changing the turns ratio (e.g., 10-1 to 20-1). Most transformers have ratio adjusting taps on the primary side. The taps provide a means of obtaining standard secondary voltages from a constant, low-voltage primary source. Most transformers are provided with taps that are 2.5, 5, 7.5, and 10 percent below the nominal voltage. Transformer connections are covered in 5.6.5.

c. The low-voltage section of the distribution substation contains low-voltage breakers and other components for controlling and metering the secondary power.

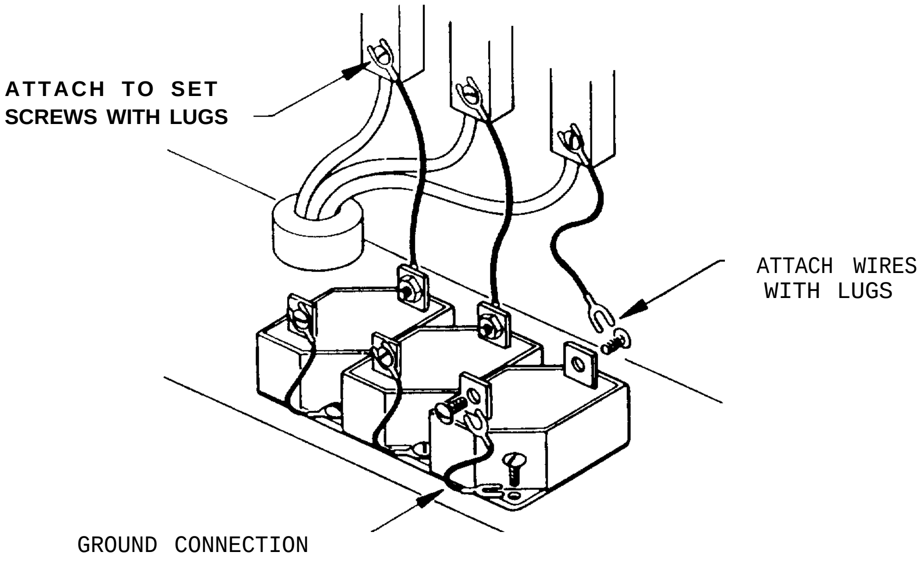
5.5.5. Substation enclosure. Steel is often used in substation construction, since the mechanical strength is hiqh, consistent, and uniform. One disadvantage of steel, particularly in coastal areas, is the gradual deterioration of the exterior coating.

5.5.6 Protective devices. Overcurrents in electrical distribution network components can be caused by either normal occurrences, such as motor starting or supply-line surges, or by natural conditions, such as lighting surges, ground faults, or line-to-line faults. In either case, overcurrent protective devices should be installed to: (1) detect the overcurrent, (2) operate selectively to protect personnel and equipment, and (3) minimize the outrage in other parts of the distribution system. Protective devices localize an overcurrent condition so that the protective device nearest to the fault on the power source side is the first to operate. However, each preceding device upstream from the fault must be able, within design limitations of current and time, to isolate some portion of the fault current. See section 9 (System protection and coordination) of ANSI/IEEE Standard 241-1983 and section 7 of FIPS PUB 94 for additional information on protective device applications.

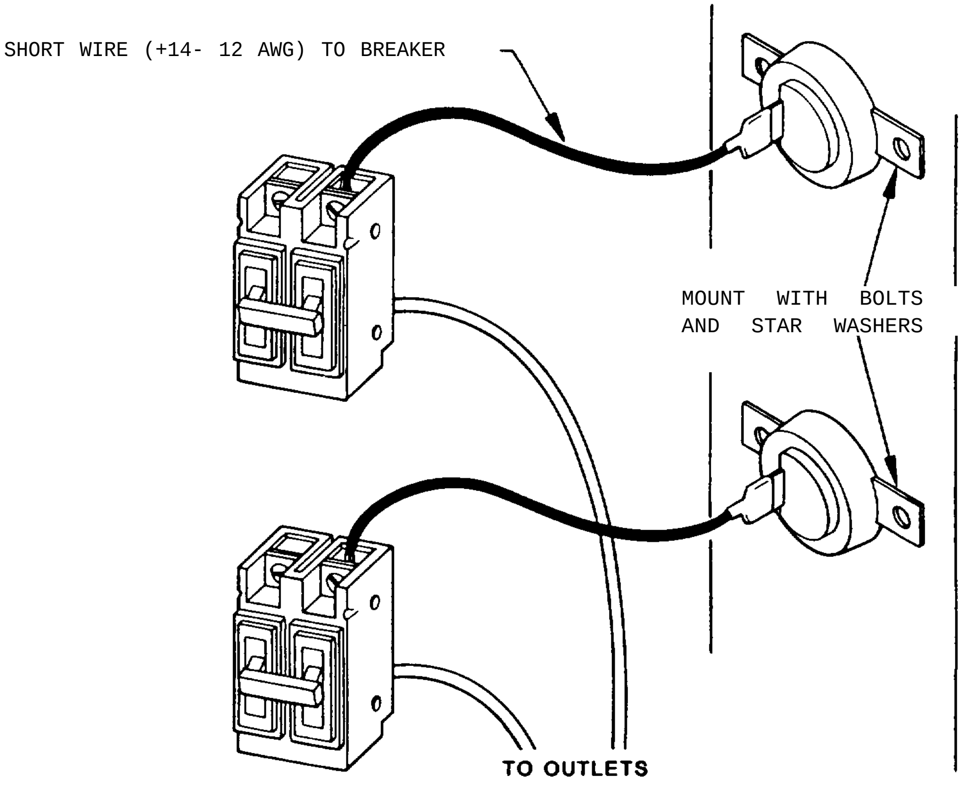
5.5.6.1 Feeders and branch circuits. Feeders and branch circuits should have circuit-protective devices coordinated to ensure disconnection of the faulted circuit as close to the fault as practicable. Protective devices should be installed and identified in accordance with safety requirements of the National Electrical Code (NEC). Grounding must conform to the standard set forth in MIL-STD-188-124; Grounding, Bonding, and Shielding Engineering and Installation Guidance for DoD facilities is contained in MIL-HDBK-419. Transient protectors, such as metal oxide varistors (MOVS), should be installed to provide transient-voltage protection for sensitive electronics equipmet. A typical mounting of MOV protectors in power distribution cabinets is shown on figure 23. For low-voltage power distribution, three basic series of MOVs (PA series, HE-DA-DB series, and BA-BB series) are currently available. MOVS of different physical size are assigned to a series that corresponds to their capability, in joules, to absorb transients.

5.5.6.2 High-voltage protection devices. Protective devices located in the high-voltage section of the substation not only protect the substation transformer(s), but also the facility. Each facility should have an up-to-date protective device coordination survey, which verifies that the protective devices in the substation, and within the facility itself, adequately protect the power-consuming equipment within the facility.

5.5.6.3 Disconnect means. The National Electric Code (NEC) requires that an overcurrent protective device must be installed on the primary side (hiqh voltage side) of the transformer as a means to disconnect the-incoming power. The disconnecting means should be: (1) a manually operated switch or circuit breaker that is equipped with a handle or suitable operating means, or, (2) an automatic switch or circuit breaker, as long as the switch or circuit breaker can be opened by hand in the event of a power failure.



A. MAIN ENTRANCE PANEL MOUNTING



B. DISTRIBUTION PANEL MOUNTING

FIGURE 23. Metal oxide varistor (MOV) installation locations.

5.5.6.4 Switches. A switch is a device for making, breaking, or changing the connection in an electric circuit or system. Switches should be used on transmission lines, in substations, switchgear, and panelboards for energizing and deenergizing electrical devices. Switches are also used for sectionalizing the power into operational and nonoperational loads. Although a switch may be designed to operate automatically, it should also have a handle for manual operation. Switches are rated according to the amount of current they will carry without overheating. Switches are normally divided into three classes: oil, air, and vacuum. For those cases where several switches should operate together, gang-operated switches should be used. Most gang-operated switches are air-break switches manufactured in 200 V-, 300 V-, and 400 V-ampere ratings in all voltage classes from 5,000 Volts or above.

5.5.6.5 Grounding of ac power distribution systems. It is important to note that the NEC defines “grounded conductor” as a conductor that is intentionally grounded (neutral); a “grounding conductor” is used to connect equipment to a grounding electrode (green wire). The NEC requires that the neutral lead be grounded at, and only at, the service disconnection and that electrical supporting structures within the substation (e.g., conduit, cable trays or race ways, wire system enclosures, or metallic power cable sheaths) should be electrically continuous and bonded to the fault-protective ground leads. The points where the ac neutral can be grounded are limited by the NEC. In general, the neutral is to be grounded at the ac power source or main transformer, or as defined in the NEC, at a separately derived source. Grounding of the neutral at a separately derived source is particularly important in large or multiple-floor buildings where a dry-type transformer (power center) is located near a computer center. Complete guidance on facility grounding can be found in MIL-HDBK-419.

5.5.6.5.1 Perferred conduit types. Shielding of communications and data circuits from ac-generated noise is improved by enclosing all power conductors in metallic conduit or continuous metallic duct. Ac fault protection and ac power conductors will not be enclosed in the same conduit with communications and data cables. There are three general types of metallic conduit acceptable for power distribution for critical DoD communications and computer facilities: rigid, flexible, and thin wall. Poly-vinyl -chloride (PVC), or similar nonmetallic construction, is not acceptable for power distribution where high reliability is a requirement. Metal conduit with set-screw type connectors should also be avoided. For maximum shielding effectiveness, metal conduit with threaded connectors should be used. To maintain this effective shield, all joints between sections of conduit should be treated with a conductive lubricant or caulk. All power conduits must be sized to accommodate the phase conductors, neutral conductor, and a fault protection conductor (green wire).

5.5.6.5.1.1 Treatment of coupling. Induced conductor voltages from lighting and EMP are directly proportional to the number and quality of couplings in a conduit run. This fact gives credence to using electrically conductive sealants on threaded couplings, or in the extreme case where maximum shielding is specified, continuous welds at threaded couplings are required.

5.5.6.5.1.2 Conduit positioning. The position and arrangement of conduits grouped together in ducts or treenches are important. Testing of several conduit grouping arrangements show that H-field induced currents will divide among the individual conduits within the group and that a higher proportion of the induced current is carried by the outermost conduits. This suggests that, where possible, the power conductors should be run in the outer group of conduits, and.more sensitive communications and data lines in centrally positioned conduit.

5.5.6.5.1.3 Use of flexible conduit. Flexible power conduit must be used sparingly, and normally, only to accornnodate vibration or movement of auxiliary power units or electric motors. Flexible conduit must be extremely high quality, and to ensure continuous shielding effectiveness, flexible conduits over 1 m (3 ft) long must be bypassed on the outside as shown on figure 24. Flexible conduits selected for high-reliability installations should have evidence of performance testing at independent test facilities for such things as attenuation, shock, vibration, temperature, and humidity.

5.5.6.6 Lighting arresters. Protective measures should be provided to keep lighting strikes from causing destructive fires, breakdown of electrical insulation, explosions, or loss of life. Protection against lighting damage may be provided by diverting lighting strikes away from the item to be protected or by limiting to a safe value the voltage imparted by a lighting strike. Protection of structures is normally provided in the form of lighting rods, masts, and overhead ground wires installed to divert strikes through a low impedance path to ground. In addition to direct strike shielding, electrical installations should be protected against voltage surges caused by induction from nearby strikes. To provide protection against these surges, lighting arresters should be installed on the transmission side of the substation. There are many types of lighting arresters available (e.g., valve type, pellet type, expulsion type, visible type). On utility-owned substations, these arresters are normally installed by the servicing company. For further information, review MIL-HDBK-419 and NFPA No. 78.

5.5.6.7 Voltage transient suppression. A voltage transient is the surge of electromagnetic energy that occurs in an ac power distribution system. This surge is caused by power transmission faults, power switching operations, lighting, or the electromagnetic pulse (EMP). Except for lighting and EMP, transients are caused by abrupt current changes in inductive components of the power distribution network. See table IX for a listing of common sources of transients. Voltage transient suppressors should be installed at points in the power distribution system where they can effectively suppress potentially damaging energy surges before they harm the equipment. Filters, UPS, and other isolation techniques as well as suppressors should be considered.

5.5.6.7.1 Detection of transients. The only reliable way to determine power system quality at a particular site is to monitor the power system with a full-time transient recorder. This recorder must be capable of reacting to

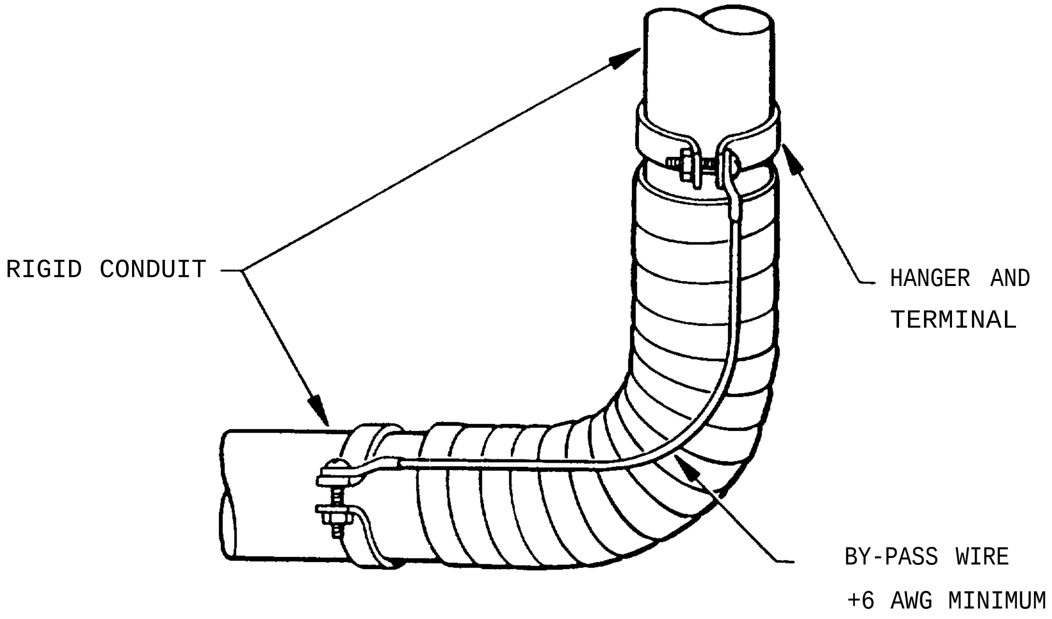


FIGURE 24. Flexible conduit bypass method.

TABLE IX. Common Sources of Transients.

MAN-MADE	NATURAL
Switching (mechanical and solid state) of reactive loads; opening and closing of switches and relays	Lighting
Fuse and circuit breaker interruption and reseatings	Movement of storm fronts
Generator and motor operation (over-speed and hunting, startup, control and shutdown)	Static charges on personnel, work surfaces, tools, etc.
Ignition systems, arc welder, precipitator operation	Static charges on long transmission lines
Fluorescent light operation	
Current in-rush	
Thyristor switching; power control	
Electromagnetic pulse (EFIP) caused from nuclear and large chemical explosions	

subsecond power changes as well as providing directional information. Directional information is useful in resolving whether the power service or user equipment is at fault. Studies in the past few years have confirmed that spikes as high as 6 kV at 120-V wall outlets are common. These studies have resulted in IEEE Standard 587, which categorizes location of indoor power outlets in relation to the service entrance, and specifies standard test waves that apply to each group. IEEE Standard 472, Guide for Surge Withstand Capability (SWC), was developed for high-voltage substation environments; IEEE Standard 28, Stdndard for Surge Arresters for AC Power Circuits, covers the utilities environment. The standard test waves are then used by manufacturers and users to evaluate transient suppression device performance.

5.5.6.7.2 Types of transient suppressors. The major transient or surge suppression devices available as design tools are: gas tubes (or gaps), MOVS, silicon avalanche diodes, and isolation using fiber optics. Table X compares the generally available transient suppressors; however, special designs of the types shown can improve the ratings for military applications. Installation of transient protection devices is covered by individual service manuals such as Army FM 11-487-4 (Air Force T.O. 31-10-24).

TABLE X. Comparison of transient suppression devices.

Device Type	Clamping thresholds (volts)	Operate time (seconds)	Highest burnout energy threshold (Joules)	Shunt capacitance (microfarads)	Possible disadvantages
Spark gaps:					
Carbon blocks	330 to 800	10^{-6}	10^{4}	10^{-5} to 10^{-6}	Power-follow, slow, variations due to changing air conditions
Ordinary gas tubes	60 to 30,000	10^{-5}	10^{3}	10^{-5} to 10^{-6}	Power-follow, slow, limited life
High-speed gas gaps	550 to 20,000	10^{-9}	10^{3}	10^{-5} to 10^{-6}	Power-follow, cost, limited life
Semiconductors:					
Forward diodes	0.2 to 0.6	10^{-9}	10^{1}	10^{-6}	Low burnout energy
Breakdown diodes	2 to 200	10^{-9}	10^{2}	10^{-2}	High capacitance
Selenium diodes	30 to 2000	10^{-9}	10^{4}	10^{-1}	High capacitance
Thyristors	25 to 1800	10^{-6}	10^{1}	10^{0}	slow response
Triggered thyristors (SCRs)	25 to 1800	10^{-5}	10^{1}	10^{0}	High capacitance
Varistors:					
MOV	40 to 8000 (higher by stacking material)	10^{-9}	10^{3}	10^{-3}	High capacitance
SIC	15 to 10,000	10^{-9}	10^{3}	10^{-3}	Poor clamping

5.5.6.7.3 Rating of transient suppressors. Most transient suppressors and arresters are rateed in joules. One Joule is defined as the energy required to transport 1 coulomb between two points having a potential difference of 1 volt. One joule is a watt-second and a kilowatt-hour is 3.6 X 106 joules. Other suppressor parameters such as capacitance, clamping voltage, standby current, and reaction time are used to select devices for particular applications. Electronic equipment being protected (complete sets or discrete components) can be assigned a disruption or destruction level in joules through actual testing or analytical methods. Figure 25 graphically portrays the range of damage thresholds for several discrete electronic components.

5.5.6.7.4 Power conditioning equipment. Because there is a need to provide “clean” power, a wide variety of power conditioning products is available, ranging from expensive UPS to single-outlet, plug-ln; surge suppressors costing a few dollars. In the middle of the price range are: voltage regulating transformers, line filters, isolation transformers, surge suppressors, emergency power sources, and various combinations of these devices. On-line battery banks used to power critical facilities are a“ helpful in absorption of transients, but should not be relied on as the transient suppressor for a load.

5.5.6.7.5 EMP generated transients. Electromagnetic pulse (EMP) and high altitude electromagnetic pulse (HEMP) are covered in considerable detail in several Government publications. Coverage in this handbook is limited to a discussion of the basic design, grounding systems, and protection of mission-critical environmental systems from the effects of EMP. In a sense, it is inaccurate to refer to several types of nuclear EMP, since this EMP involves electromagnetic fields produced by a nuclear explosion. However, the explosion position in reference to an affected system has such a significant influence on the amplitude and frequency characteristics of the EMP that it is useful to categorize it. High-altitude EMP (HEMP) refers to the large amplitude, early-time EMP produced by a nuclear burst at an altitude above 30 km (19 miles). Surface-burst EMP is produced by a nuclear burst within 0.2 km (650 ft) of the earth's surface. Air-burst EMP is produced by a nuclear burst at intermediate altitudes from 2 to 20 km (1.2 to 12 miles). System-generated EMP (SGEMP) is produced by direct interaction of high-energy photons with the system, rather than with interaction with atmospheric components. Magnetohydrodynamic EMP (MDH-EMP), like HEMP, is generated by a high-altitude nuclear burst, but is distinguished from HEMP by a later time occurrence, smaller amplitude, and a distinct generation mechanism. TABLE XI lists the generalized characteristics of the various types of EMP.

5.5.6.7.5.1 Balanced design of facilities. Some DoD facilities will be required to survive HEMP, and some may also be rewired to survive surface or air-burst nuclear effects (includes blast, shock, ‘thermal, and radiation). Depending on the stated survivability requirements for a surface or air-burst nuclear environment, facility EMP protection against the low-altitude threat will usually exceed that required for HEMP. In any event, the level of EMP protection against air and surface nuclear burst must be in balance with the design capability of the overall facility to withstand other nuclear effects. Figure 26 illustrates the widespread coverage expected from HEMP.

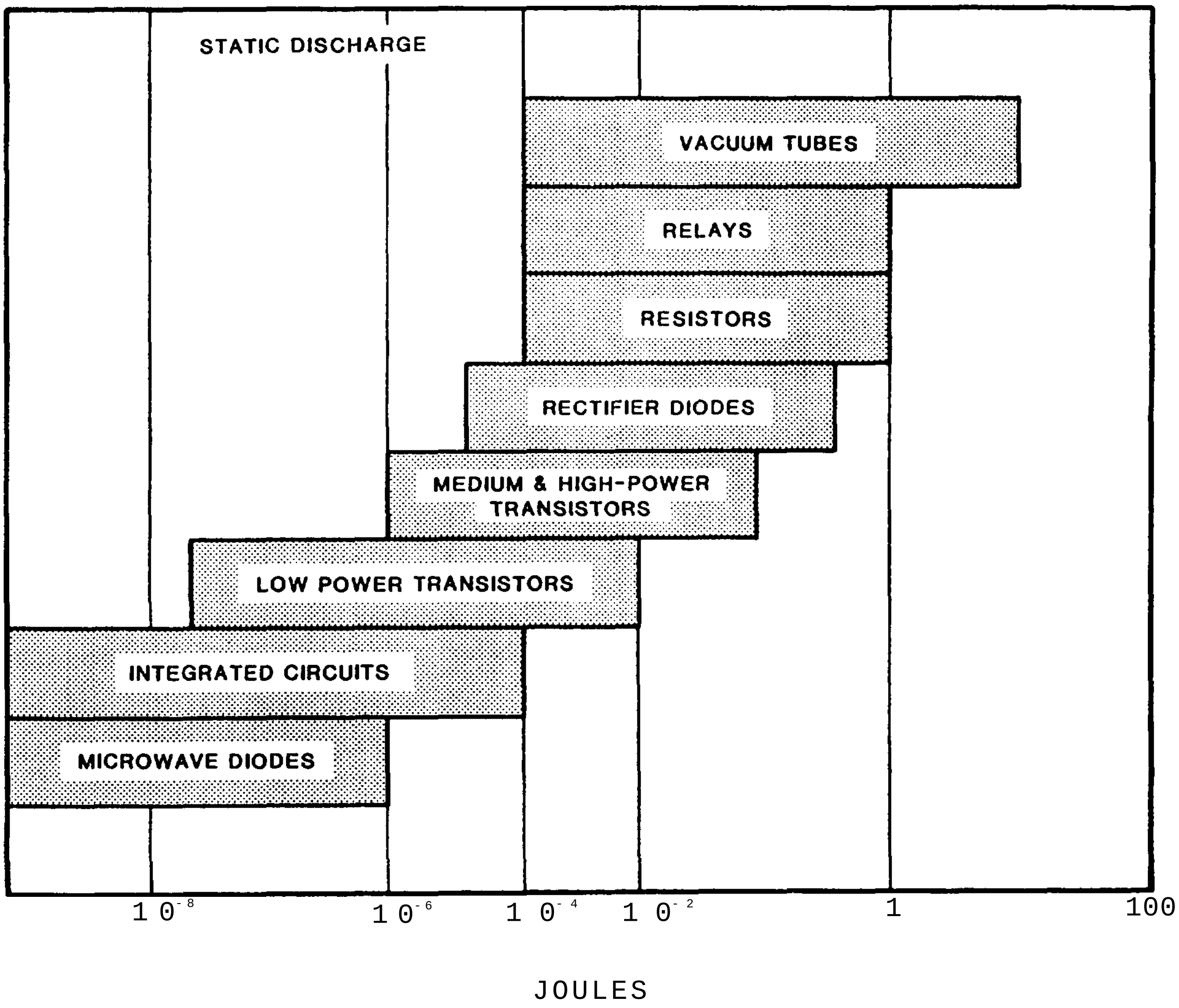
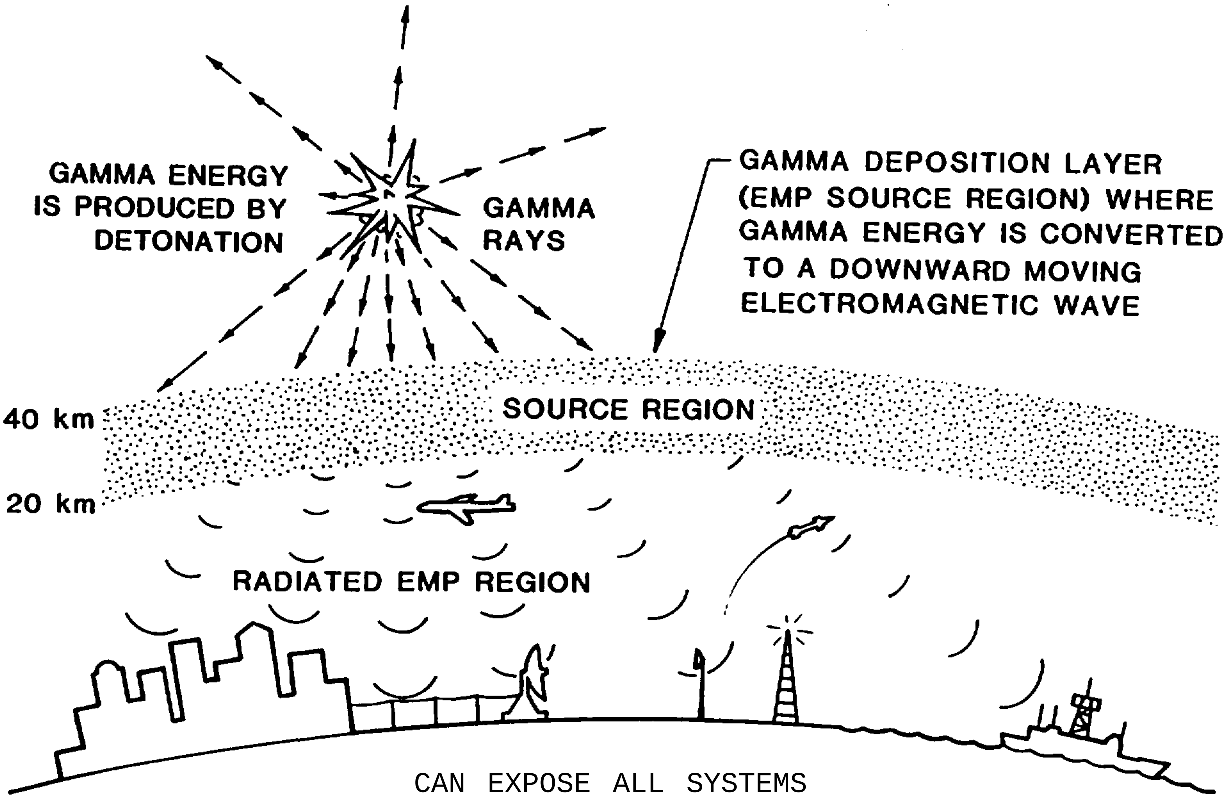


FIGURE 25. Component damage levels in joules.

TABLE XI. EMP environments summary.

TYPE	PEAK AMPLITUDE	CHARACTERISTICS
HEMP	50 kV/m	
Surface burst	1 MV/m	FEW ns to l s
Source region	10 kV/m	1 s to 0.1 s
Radiated region	10 kV/m	1 s to 100 s
Air burst		
Source region	Similar to surface burst	Components like a HEMP surface burst
Radiated region	Less than HEMP	
SGEMP	100 kV/m	FEW ns to 100 ns
MHD-EMP	30 V/km	0.1 s to 1000 s

5.5.6.7.5.2 Comparison of EMP with lighting. Because the nuclear HEMP arrives at the earth’s surface as a plane wave rather than as a stroke channel, the melting, charring, and splintering effect associated with direct lighting strikes do not usually occur with the EMP. The EMP exerts its influence through induced effects. That is, the very large electromagnetic fields of the EMP induce large voltages or currents in antenna-like elements o9f equipment or structures. For example, a 5-meter-high vertical conductor (monopole antenna) exposed to a 50-kV/m incident electric field will have an open-circuit voltage of 500 kV induced at its base. This means that conductors over a few meters long are no longer electrically short. Even though a 7-meter-long ground wire on a transformer pole may be treated as an inductance when modeling the effects of lighting; 7 meters is approximately twice the distance an EMP wave will progagate during buildup. In investigating EMP effects, conductors over a few meters long must be analyzed as transmission lines, rather than as lumped capacitive, resistive, and inductive elements. In addition, small inductances and capacitances that are



CAN EXPOSE ALL SYSTEMS
WITHIN LINE OF SIGHT

FEATURES OF HIGH ALTITUDE EMP (HEMP)

- WIDE AREA COVERAGE
- HIGH FIELD STRENGTHS (50 KV/M)
- BROAD FREQUENCY BAND (10 KHz - 100 MHz)
- ABSENCE OF MOST OTHER NUCLEAR WEAPONS EFFECTS

FIGURE 26. Coverage and character sties of HEMP.

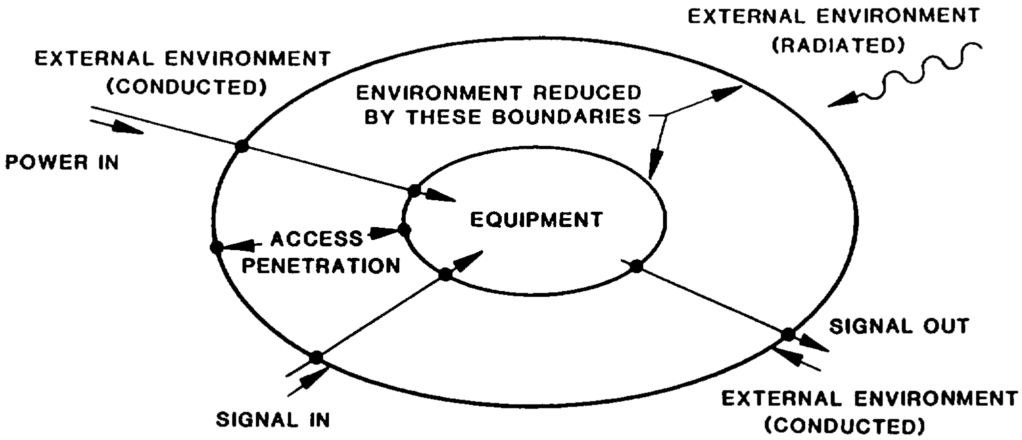
negligible in lighting analysis become important in EMP analysis due to the large rates of change associated with the leading edge of the EMP. The primary effect of the EMP is the production of large voltages or currents in conductors such as power lines, buried cables, antennas, etc. These induced currents and voltages may then cause secondary damage or malfunction. Logic circuits, in which information is transferred as a train of pulses, are particularly susceptible to transients of the type induced by the EMP. Even small transients in these circuits can cause a false count or status indication that will lead to an error in the logic output, and large transients can destroy the junctions of solid-state components used in these circuits. Furthermore, the techniques used for protecting equipment from the slowly rising lightning transients are not necessarily effective against fast-rising EMP-induced transients.

5.5.6.7.5.3 Objective of EMP hardening. The main objective of all EMP hardening is to prevent the transient produced by a nuclear detonation from causing a system malfunction that degrades mission performance. Previous discussions in this handbook have concentrated on the application of discrete protectors against the effects of EMP; however, the only completely effective method uses a barrier or topological scheme. A topologic boundary system, such as illustrated in figure 27a, uses electromagnetic shields, transient suppression devices, and isolation elements in harmony to assure that the mission will not be degraded during EMP conditions. If a facility is completely self-contained, as shown in figure 27b, with no connection to outside communications, power, or other utilities, then a “Faraday cage” offers the ultimate protection for electronic equipment. The "real world" does not lend itself to this approach; therefore, some form of external metal shielding is required for military systems that must survive nuclear weapons effects. This external surface may be integrated in the building walls of a communications facility, the skin of a missile, or the equipment cabinet itself. Physically burying a structure in earth or rock can also make a significant contribution to overall facility shielding. An exterior metallic surface diverts currents on penetrations and reflects or attenuates impinging electromagnetic radiation. Table XII lists the performance of some typical sheilded rooms. Some form of a shielded room or cabinet must be used at every DoD facility that is required to survive the effects of EMP.

5.5.6.7.6 Use of shielded enclosures in transient protection. Shielding effectiveness (SE) is expressed in decibels (dB) which is the unit normally used to express differences in signal strengths. The dB is a unit used to express a ratio of two numbers. It is not an absolute unit, but a ratio that is used to compare two signals, voltages, currents, or powers.

A decibel is equal to ten times the common logarithm (to base ten) of the power ratio:

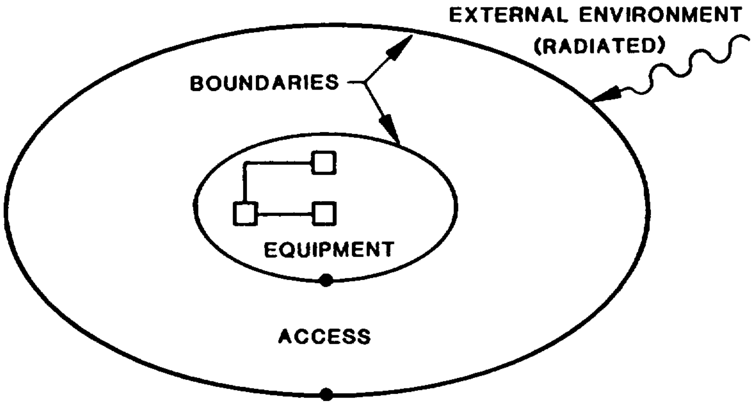
$$\text{Number of decibels} = 10 \text{ Log} \frac{(P_1)}{(P_2)}$$



PENETRATION TREATMENT IS PART OF BOUNDARY

- A "COMMUNICATIONS CENTER"
  - EXTERNAL POWER
  - RECEIVE SENDS MESSAGES ELECTRONICALLY
  - UTILITIES (WATER, SEWAGE. TELEPHONE) PENETRATE

A. MOST SYSTEMS APPEAR LIKE THIS



- AN "ANALYSIS CENTER"
  - COMPUTER GENERATES PAPER REPORTS
  - EQUIPMENT POWERED BY BATTERY
  - ACCESS DOORS CAN BE MADE ALMOST CONTINUOUS WITH STRUCTURE

B. RARELY LIKE THIS

FIGURE 27. Generalized topological protection.

TABLE XII. Performance of some typical shielded rooms.

Room description	Frequency (kHz)	Magnetic shielding effectiveness (dB)	
		(max.)	(min.)
Copper screen cell	15	61	56
Styrofoam core, sheet metal skin	200	97	96
Hollow core, sheet metal skin with piano hinge and finger stock on door	15 200	100 118	81 108
Sheet metal bonded to plywood, double finger stock on door	1000	100	80
Continuously soldered, zinc-electroplated sheet metal with commercial finger stock on door and filtered power	14 100	70 --	65 90
Inert-gas-welded sheet steel, double finger stock on door	14 200	90 130	74 106
Double shielded, continuously inert-gas-welded, low-carbon sheet steel with expanding-panel sliding doors	1 1 15 100	-- 62 108 120	25 52 92 107
Partitioned room seams - continuously inert-gas-welded sheet steel with triple-finger stock on door	0.15 1.0 5.0 15	104 122 80 20	73 -- -- --

Where P_1 is normally the larger power and P_2 is the smaller, one decibel of attenuation means that a signal has dropped to 0.794 of its original power. One decibel of gain means that a signal has increased to 1.259 of its original power. Table XIII can be used to convert some of the common dB to power ratios. Voltage and current ratios can also be expressed in decibels. Power is proportional to the square of the amplitude of a signal. A power ratio of 100 is equivalent to an amlllitude ratio of 10. Therefore. where the two current level; are 1_1 and 1_2, or; the two voltage levels are V_1 and V_2, we have:

$$\text{Number of decibels} = 20\ \text{Log}_{10}\ (I_1/I_2)\ \text{or}\ \text{Log}_{10}\ (V_1/V_2)$$

5.5.6.7.6.1 Shielding effectiveness. The effectiveness of a metallic shielded enclosure (or shield) is a measure of its ability to attenuate electromagnetic energy, which can be expressed as:

$$\text{Shielding effectiveness (SE (in dB))} = 20\ \text{Log}_{10}\ E_1/E_2$$

Where E_1 is the measured field strength in volts/meter without the shield and E_2 is measured field strength within the enclosure, at a fixed test distance.

5.5.6.7.6.2 Factors affecting shielding effectiveness. When designing a shielded enclosure for a specific application, the thickness, conductivity, and permeability of the shielding material are the factors used to determine the low-frequency, magnetic-field performance. Electric field shielding at low frequencies is due primarily to reflection and absorption losses as shown on figure 28.

a. Absorption can be expressed as:

$$A(\text{dB}) = 3.338\ T\ (FGM)^{1/2}$$

Where A is absorption loss in dB, T is material thickness in roils, F is frequency in MHz, G is conductivity relative to copper, and M is magnetic permeability relative to free space.

b. The performance of the shielded enclosure at frequencies greater than 10 MHz is limited by shield discontinuities such as: seams, joints, door design, and penetrations. Shields must maintain continuous and uniform contact with other sections of the enclosure to eliminate rf leakage.

The thickness of steel walls used in shielding typically range from 22-gauge (0.8 mm, 0.03 inches) to 000-gauge (9 mm, 0.375 inches). The wall thickness selected will depend on the threat level and the susceptibility levels of the equipment to be protected. For most low-altitude or near-surface burst conditions, the wall thickness required for protection against EMP will range from 22- to 10-gauge [0.8 mm, 0.03 inches to 3.5 mm, 0.14 inches)]. Wall thickness of up to 9 mm (0.375 inches) for EMP protection is necessary when protecting from the near-field effect of a surface burst, or when thickness is dictated by structural rather than EMP criteria. A shield of 9 mm (0.375 inches) low-carbon, full-penetration welded steel gives more than 45 dB of shielding for all frequencies above 100 Hz.

TABLE XIII. Conversion from power ratios to dBs.

1 - Decibel attenuation means that 0.79 of the input power survives

3 - Decibels attenuation means that 0.50 of the input power survives

10 - Decibels attenuation means that 0.1 of the input power survives

20 - Decibels attenuation means that 0.01 of the input power survives

30 - Decibels attenuation means that 0.001 of the input power survives

40 - Decibels attenuation means that 0.0001 of the input power survives

50 - Decibels attenuation means that 0.00001 of the input power survives

60 - Decibels attenuation means that 0.000001 of the input power survives

NOTE: In using the shielding effectiveness formula (i.e., $SE \text{ (in dB)} = 20 \text{ Log}_{10} E_1/E_2$), electric fields are involved, and the logarithm multiplier is 20 instead of 10. This means that the ratio that results in a shielding effectiveness of 120 dB (a reasonable design goal) is a reduction of 1,000,000 to 1, or 0.000001 of the field present externally can be measured internally. This corresponds to the 60-dB line of this table which deals with power. This table enables quick conversion of a power ration to dB and vice versa.

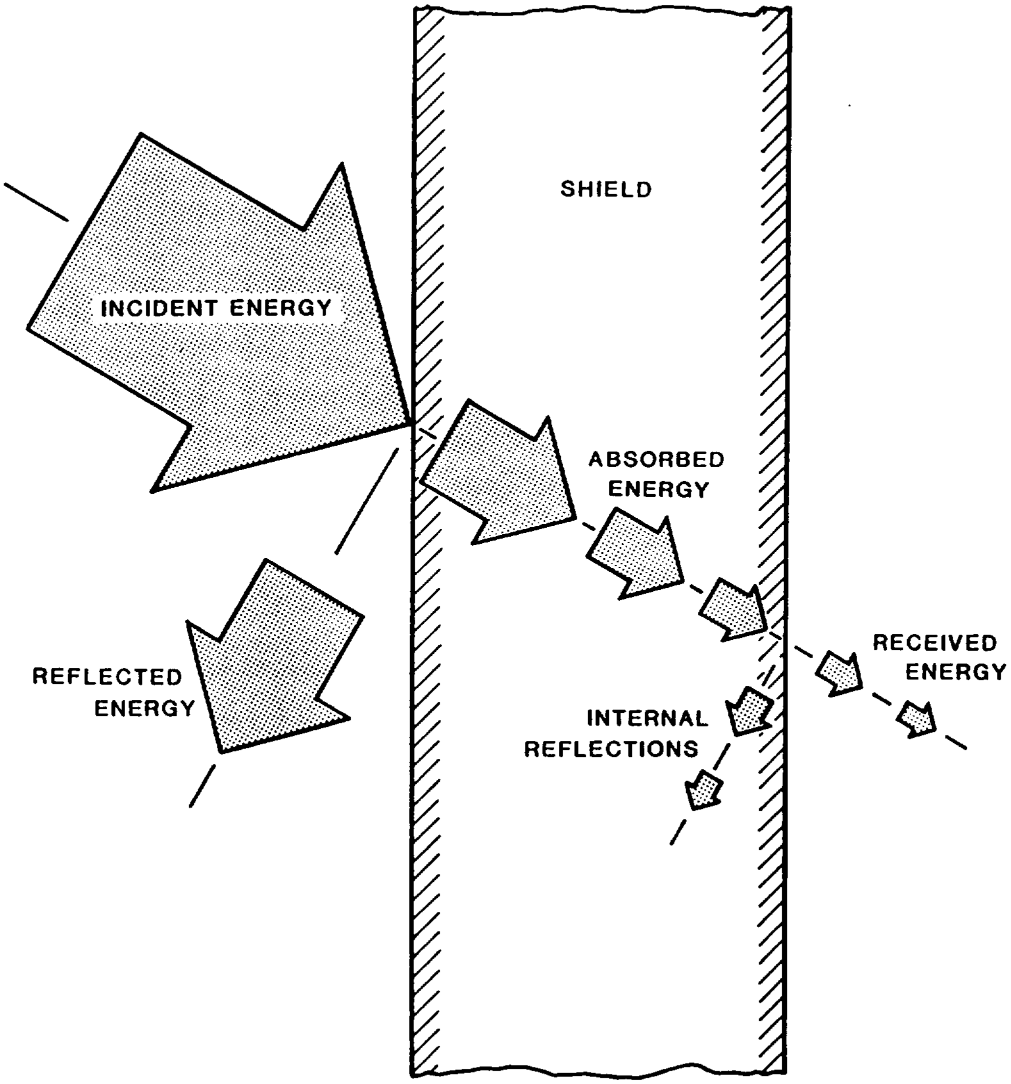


FIGURE 28. Absorption and reflection loss from a shield.

5.5.6.7.7 Control concepts for shielded enclosures. A shielded volume can be a building, a room, or a cabinet within a room that serves to prevent electromagnetic fields from coupling to interior electrical conductors. To fulfill its purpose, EMP shielding excludes from the designed volume the electromagnetic fields associated with both incident and coupled EMP on utility and communication lines, and the shield itself. Sheilding provides two other benefits. One is a well-defined topology that reduces the difficulty of validation (see figure 27). Further, if it is a validated high-performance topology layer, it will reduce the shielding requirement and electronic retrofit concerns. The second benefit is that a continuous shield provides an earth reference and a diversion plane for transient suppression.

5.5.6.7.7.1 Ideal shielded enclosure. The ideal shielded enclosure design would not have any penetrations. But, the real world requires personnel equipment access as-well as communications and utility penetrations. A shield that completely encloses a volume with a conducting surface is called a topological shielding layer. The effectiveness of such a shield is degraded when openings and penetrations of this layer occur, so it is necessary to apply stringent penetration protection to a shielded volume solve real-world coupling problems. An electromagnetic volume shield is effective only to the extent that EMP transients on penetrations are controlled and the conducting surface is continuous to allow a free flow electrons over all portions of the surface of the shielding layer.

5.5.6.7.7.2 Control of shield penetrations. Control of the shield penetrations includes both handling of EMP coupled to cable shields and suppression of transients, which are induced on signal and power leads coming into the protected volume. It is desirable that large currents be diverted away from the shielding surface even before a cable reaches the shield. At the penetration point, it is essential that remaining shield current be conducted on the outside of the shielding surface rather than through it, as illustrated on figure 29. Another source of shield penetration stems from the fact that all metals have a finite, rather than an infinite, conductivity. Incident waves will diffuse through a metal resulting in a small transmitted field into the interior. The field strength of the propagating wave decreases as the wave penetrates deeper into the conducting medium. The rate of attenuation increases as the field frequency and the electrical conductivity of the medium increase. Diffusion of fields through a highly conductive shielding surface is usually a small contributor to internal fields. Special treatment is required for penetrations in order to maintain shield integrity. The ideal is that there should be no conduction of EMP energy from the outside to the inside of the shield. External conductors should be grounded outside the shield. Internal conductors should be grounded inside the shield, and these two ground systems should not be connected. Figure 30 provides examples of proper and improper treatment of shield penetrations.

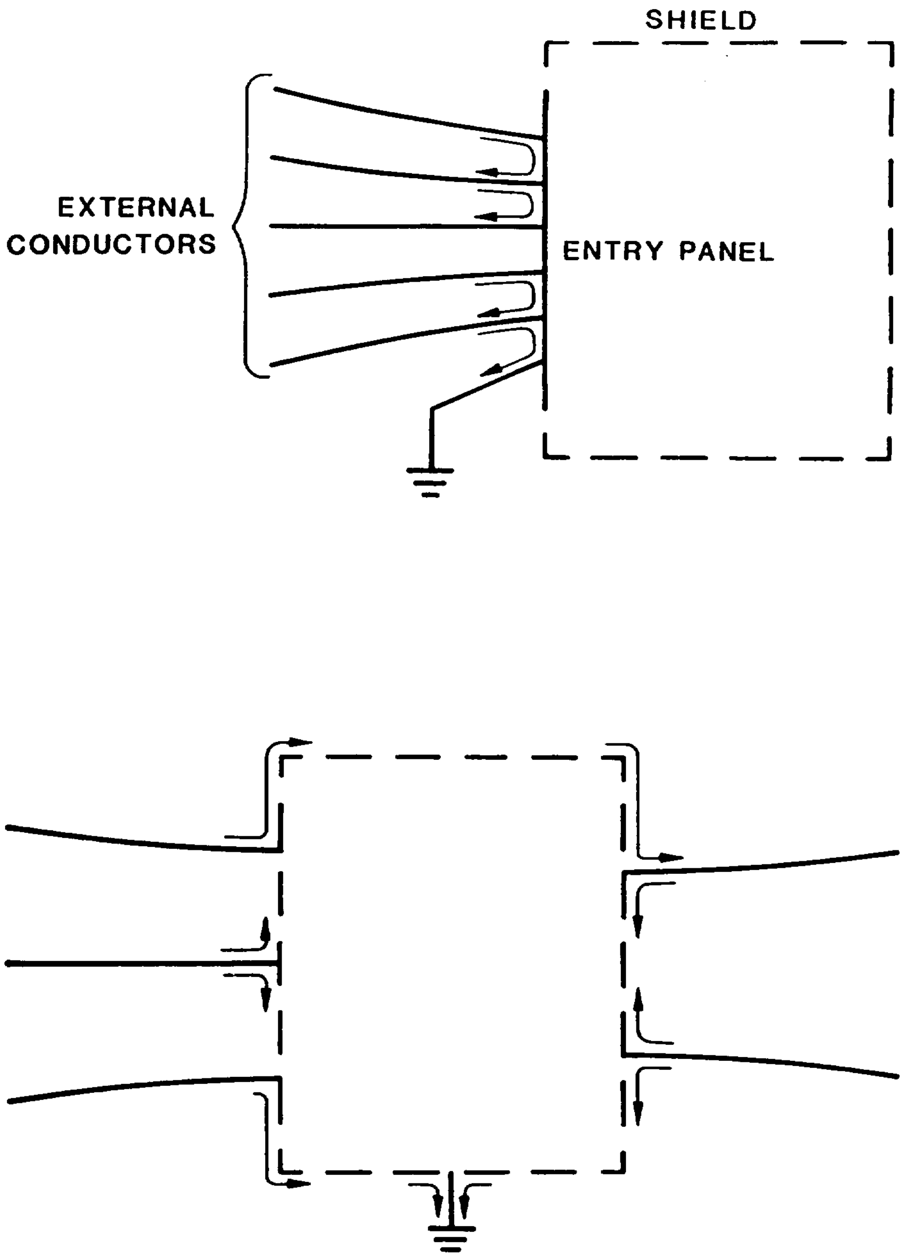


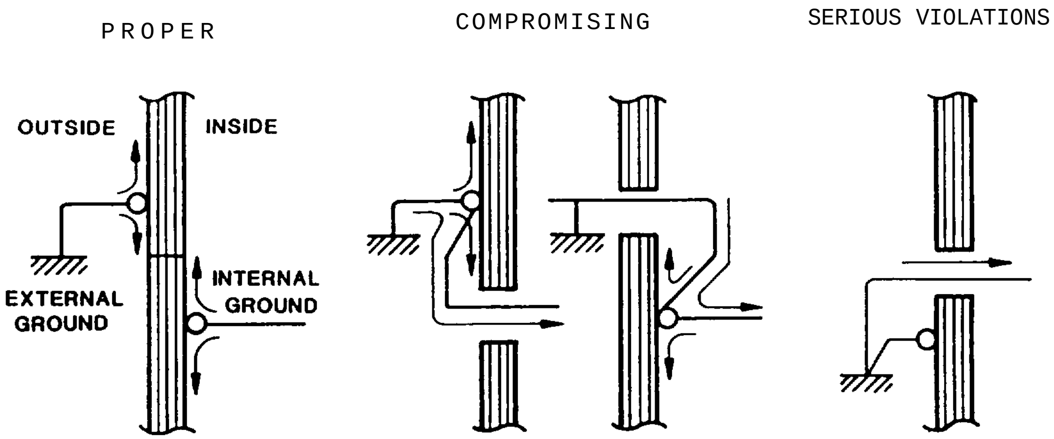
FIGURE 29. Attachment methods for external conductors.

5.5.6.7.8 Transient protection concept. Because the EMP is a transient that contains considerable power at frequencies approaching 100 MHz, the analysis of EMP effects is a transient analysis. Although some significant differences between the EMP and lightning have been discussed earlier in this handbook, the results of extensive transient analysis related to lightning are beneficial to the analysis of EMP effects on power systems and components. One of the problems encountered in the analysis of the coupling and propagation of EMP-induced transients is determining the electrical properties of components (such as transformers, motors, etc.) at frequencies other than their normal operating frequencies (60 to 400 Hz). However, for many transmission-line components, analytical techniques and component characteristics have been developed for lightning and switching transient analysis that are applicable for the frequency spectrum below 1 MHz. A facility atmospheric monitor, capable of time tagging the arrival of certain types of lighting, and correlating this activity with facility electronic malfunctions, is useful in detecting vulnerabilities to both lightning and the EMP. A dual-output monitor that detects lightning and fast-rising HEMP can provide an indication to those DoD facilities not initially affected by blast and thermal effects, to initiate “button-up” procedures.

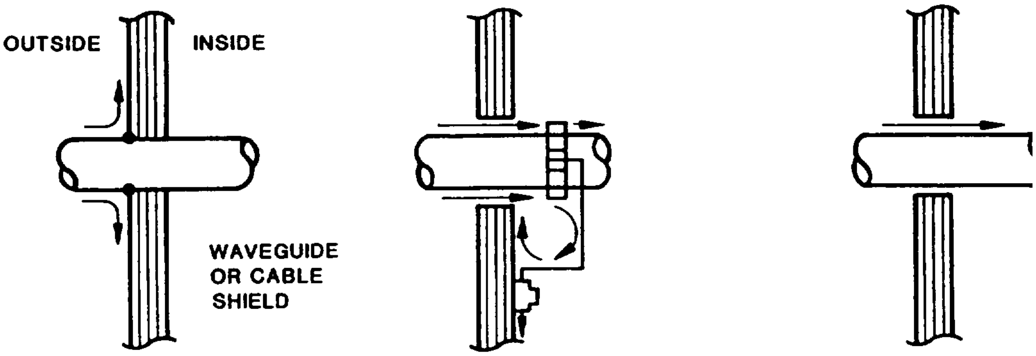
5.5.6.7.8.1 Conductor treatment. Figure 30a provides an example that can be used in grounding conductors. Shield integrity (effectiveness) will be compromised if the equipment inside the shield is grounded on the shield exterior, or if external conductors are grounded on the shield interior. serious violation illustrated on figure 30a is the connection of interior equipment to an exterior ground. The result is that the external conductors readily accessible to high EMP fields are directly connected to internal equipment. Figure 30b illustrates techniques that may be used in treatment of “groundable" conductors such as a waveguide or cable shield. The proper technique usually is connection by welding of the external shield to the facility exterior. A serious violation occurs if groundable conductors, which can collect EMP energy outside the shield, enter the shield without being properly grounded. Figure 30c gives examples of the treatment of insulated conductors. The proper treatment is a surge arrester or electronic filter located at the boundary of the shield and connected to the shield exterior. The shield is compromised if the arrester or filter is inside the shield and connected to the shield interior. A serious violation occurs if there is no filter or arrester.

5.5.6.7.8.2 Treatment of other shield penetrations. Penetrations through apertures such as windows, doors, or ventilation outlets allow external fields to penetrate into the protected space inside the shield, where they may interact with interior circuits. The possible treatments of these shield violations are:

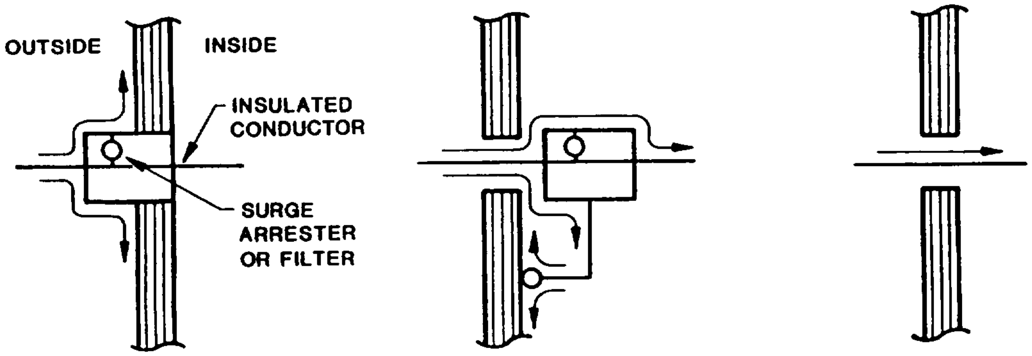
- Remove the aperture.
- Cover the aperture with a solid
- Use waveguide-beyond cutoff techniques (singly or in a honeycomb array).
- Cover the aperture with perforated metal plate.



A. GROUNDING CONDUCTORS



B. GROUNDABLE CONDUCTORS



C. INSULATED CONDUCTORS

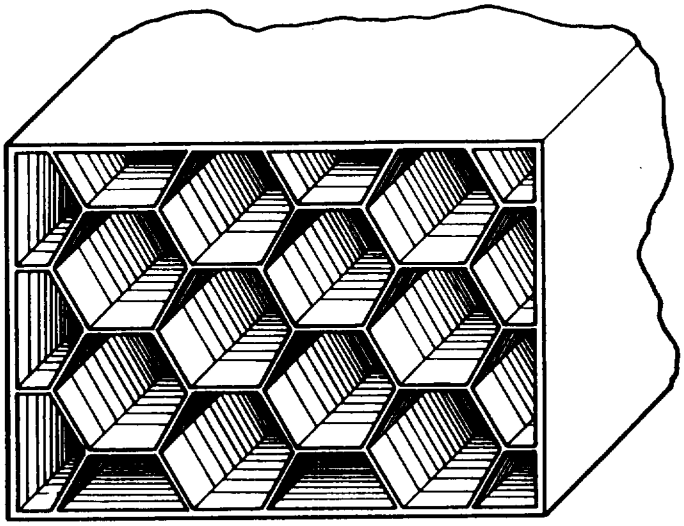
FIGURE 30. Treatment of Penetrations.

a. Regularly used passageways through the shield are sometimes provided with doors that are fitted with conductive gaskets at each end of the waveguide tunnel. This is because the waveguide is too large to be beyond cutoff at the highest frequencies in the EMP spectrum. Doors at both ends of the tunnel can be interlocked so that only one can be opened at a time, or they can be bypassed (left open), except during “button-up” conditions. Cargo doors and equipment access hatches that are infrequently used can be sealed with gasketed metal covers when not in use. The effectiveness of gaskets is controversial unless maintenance procedures are carefully controlled.

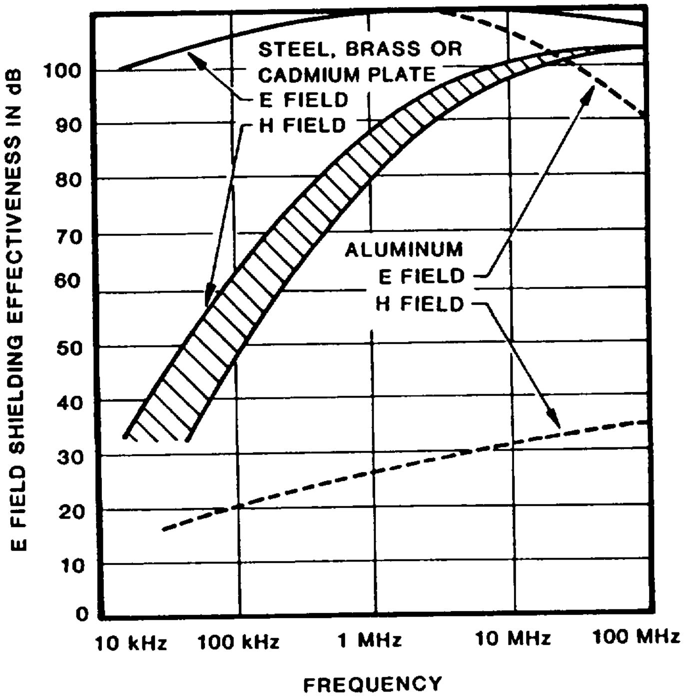
b. Openings for ventilation can be covered with a honeycomb array of waveguides (beyond cutoff) to allow airflow without permitting excessive EMP penetration of the shield as shown in figure 31. Arrays used for this purpose must be welded or soldered at the crossings to ensure good contact. It is preferred that apertures caused by fabrication be eliminated by continuous welding, brazing, or other fused-metal joining techniques. The advantage of fused-metal joining is that its effectiveness is understood and does not need extensive retesting in a hardness surveillance program. Refer to MIL-HDBK-1195 for additional information on shielded enclosures.

5.5.6.7.8.3 Use of fiber optics in transient protection. Fiber optics are attractive for use in EMP mitigation designs, but access apertures and protection of the fibers against radiation or physical damage for runs external to the shield are required. Figure 32 illustrates this concept. Table XIV lists the advantages and disadvantages of fiber optic systems.

5.5.6.7.8.4 Use of filters in transient protection. Spectrum limitations using filters containing resistance, capacitance, and inductive elements is also effective in reducing the effects of EMP. Even though filters can provide effective transient protection, if used improperly, filters may be ineffective, or can make the coupling worse. It is important to understand the limitations of filters to avoid the problems that past experience has uncovered. In general, filters do not absorb energy; instead, they reflect it. They provide a high input impedance (choke input), or a low impedance to ground (capacitor input) that constitute an impedance mismatch for the attached transmission line (cable). This may be acceptable when the filter is mounted on the shield enclosing the facility. The benefit is less clear, however, when filters are used selectively in an unshielded area, since the reflected energy may cause EMP levels to increase elsewhere. As a general design rule, it is advisable to determine where the reflected energy will go when a filter is added, even if the facility is fully shielded. Table XV lists some of the advantages and disadvantages of filters. Although filters can remove enercjy from the EMP and lighting that is outside the passband required for operation of a circuit, there is still the problem of preventing equipment damage from the transient energy passed by the filter. There is also the possibility that imperfect impedance matching of a filter can result in ringing voltages that are intolerable, especially in power circuits where the load impedance is not well known and varies widely. The solution to this impeaance problem is to use a device with nonlinear voltage/current



A. HONEYCOMB VENTILATION DUCT



B. SHIELDING EFFECTIVENESS FOR 1.25 cm THICK HONEYCOMB WITH CELL WIDTH 1.25 cm

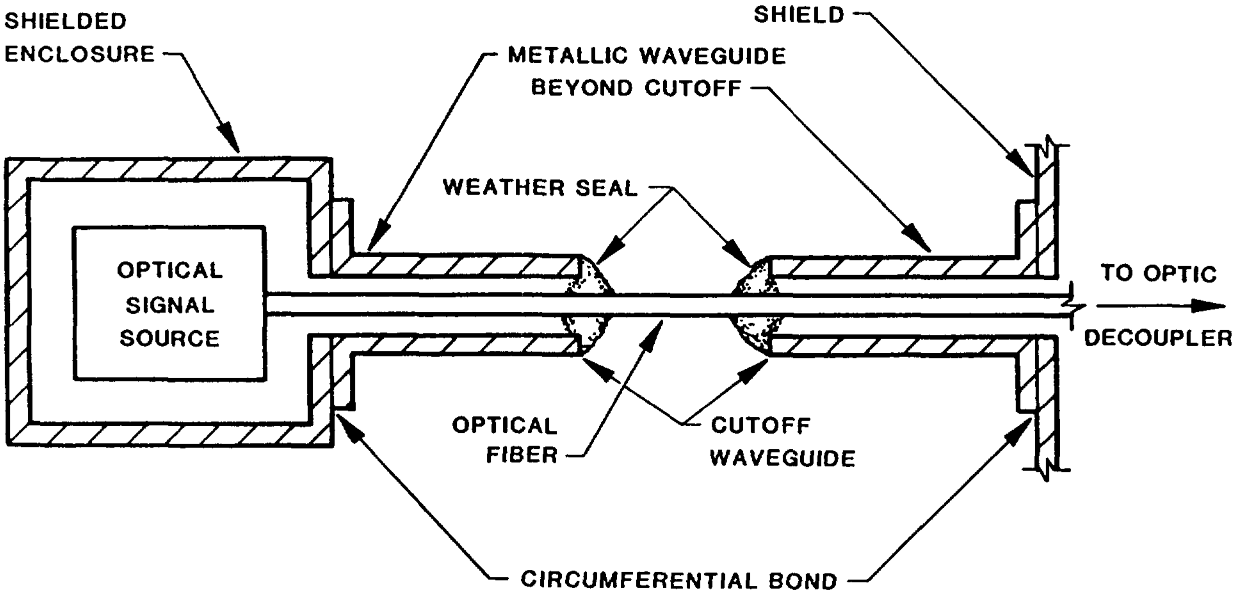


FIGURE 32. Example of fiber optic shield penetration.

TABLE XIV. Advantage and disadvantages of fiber optic systems.

ADVANTAGES	DISADVANTAGES
Eliminates EMP coupling on cables between end points	Higher cost than EMP filters on copper lines for virtually all facility applications
Can eliminate large number of electrical penetrations (communications circuits) - Fewer penetrations reduces EMP surveillance task - All failures are fail safe for EMP coupling	Reliability could be better or worse than conventional cable drivers, depending on design Must protect end terminals from EPIP, particularly the power inputs and signal lines
Immune to lighting transient effects on cable (eliminates stress on interface and wearout)	Detectors are potentially vulnerable to radiation effects (sensitive to photons)
Do not need nonlinear voltage limiters at penetrations - No spark gap wearout - Fiber optic systems do not generate noise as a result of EMP event	Limited distance without repeaters, but technology is improving rapidly Fiber optic cable could be affected by radiation (darkening of the glass)
Can multiplex many channels onto one fiber, or use one channel per fiber	Long fiber optic cable runs may be subject to deliberate or accidental destruction by blast
Can use several optical wavelengths simultaneously (wavelength-division-multiplexing)	
Can handle extremely large bandwidths or data rates on one fiber optic cable	
Can decrease data errors with error controls	

TABLE XV. Advantages and disadvantages of filters.

ADVANTAGES	DISADVANTAGES
Linear, passive response is predicated. Response tests at low level can easily be scaled to high level	Response is affected by source and load impedances which are generally unknown and variable. Must test periodically to verify effectiveness
Effective against both upset and burnout. Reduces the out-of-band signals with minimal effects on in-band	Cannot suppress in-band EMP transients. May effect in-band by slowing up rise and fall times of data
Large selection of off-the-shelf components available	Existing components may fail under electrical stress. Must test to verify survival
Capacitor on input can slow up rise time for easier clipping with limiting device	Filter must survive early current surge. Capacitor elements are subject to puncture during high level transients
Available in miniaturized form	Lower-rated internal components tend to fail easier under electrical stress
High capacitance characteristic tends to reduce voltage levels	Some circuits cannot tolerate high capacitance, e.g., capacitive fuel probes, field-exciter regulators on generators, two-phase motors, and high-data-rate digital lines.
Can protect over a wide range of frequencies	Packaging of filters can be critical to maintaining effectiveness over the full frequency range
Fairly rugged under normal operating conditions with minimal service required	Units required to function under abnormal stress may require special relays to dynamically monitor leakage current of components

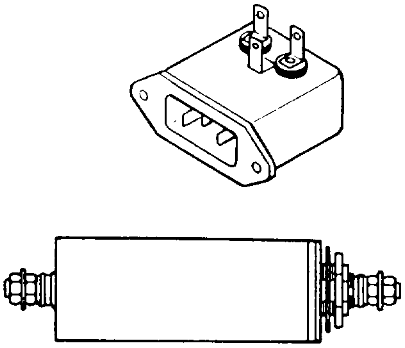
characteristics. The ideal onlinear device passes no current until the voltage across it reaches a threshold, after which the device conducts whatever current is necessary to keep-the voltage across it from going any higher. Real devices do not have such sharp transitions, but have acceptable high impedances below the threshold voltage, and acceptable low impedances above the threshold. Such devices are usually rated by breakdown voltage and joules. (A Joule is a watt-second and a unit of work.) Nonlinear devices are placed so that they short out damaging pulses or shunt them to ground. This effectively limits the voltage beyond the protective device to a value that the end equipment can tolerate. With the very fast rise times of the EMP, it is important that there be a minimum impedance in series with the device. Even the inductance associated with a few centimeters of straight wire can allow significant voltages to pass the device without attenuation. Nonlinear devices include avalanche diodes, MOVS, spark or gas gaps, and tyristors. Table XVI compares the common transient protection devices available. Figure 33 shows typical packaging details.

5.5.6.7.8.5 Use of discrete components in transient protection. Semiconductor diodes have a reverse breakdown (avalanche) characteristic that is useful in voltage reference or voltage regulation circuits. This constant voltage characteristic is also one that can be used for surge suppression. The reverse breakdown is caused by two effects - the zener effect, which is dominant in diodes with reverse breakdown voltages of less than about 6 volts, and the avalanche effect, which dominates above 6 volts. Breakdown diodes are desirable for surge protection due *to* their fast response time (10-1 2 seconds is theoretically possible) and low leakage currents in the "off" condition. The biggest disadvantage is that most breakdown diodes are not designed to handle the high currents necessary to suppress lighting and EMP pulses. In fact, many of them are almost as susceptible to damage as the devices that they are supposed to protect. Breakdown diodes that have been specifically designed to handle large, fast transients are constructed with more than ten times more surface and junction area than a common, l-watt, breakdown diode. These devices also have internal heat sinks bonded to each side of the silicon chip. These devices also have internal heat sinks bonded to each connection to the diode. The large surface-area junction, and internal heat sinking, allow the device to absorb high energy pulses associated with the EMP or lighting without damage.

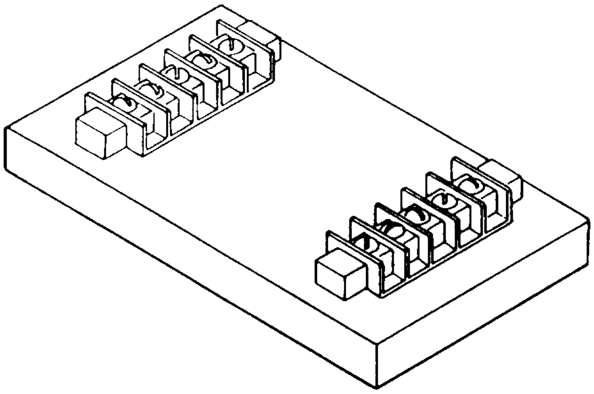
a. Spark gaps (in atmospheric pressure) are in wide use for lighting protection. Such spark gaps. however, cannot respond to transients as fast as those casused by the EMP. By enclosing and controlling the type and pressure of the gas in a gap, ionization characteristics can be vastly improved for transient protection. Additionally, the speed of ionization of a gas gap can be improved by adding a small amount of radioactive material such as tritium or thorium. This material causes a small amount of the gas to be ionized at all times. The preionized gas then avalanches and causes rapid ionization of the rest of the gas in the presence of a large electric field. Once a gas is ionized, it will stay ionized as long as current continues to flow. The voltage across the device drops drastically from the quiescent to the ionized states. This presents the problem of extinguishing

TABLE XVI. Typical arresters and protective devices.

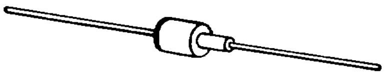
TYPE	REFERENCE FIGURE 33	BREAKDOWN OR SPARKOVER VOLTAGE	MANUFACTURER
Filters	A	N/A	Filtron, RFI, RTE, Corcom et. al.
Data line protectors	B	20 - 300	Numerous
Low-voltage protectors (diodes, Movs)	C	5.0 - 400	Motorola, GE, C.P. Clare, General Semiconductor et. al.
Single-gap gas-tube	D	75 - 2000	C.P. Clare, Joslyn
Tubular varistor	E	25 - 150	GE, Siemens
Dual-gap (three-electrode) gas-tube arrester	F	75 - 2000	C.P. Clare, Joslyn
Secondary power	G	130 - 2800	Joslyn, Dale, GE, Siemens, Panasonic, et. al.



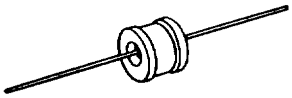
A. FILTERS



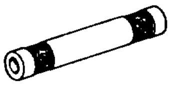
B. DATA LINE PROTECTOR



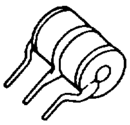
C. LOW VOLTAGE PROTECTOR
(DIODE)



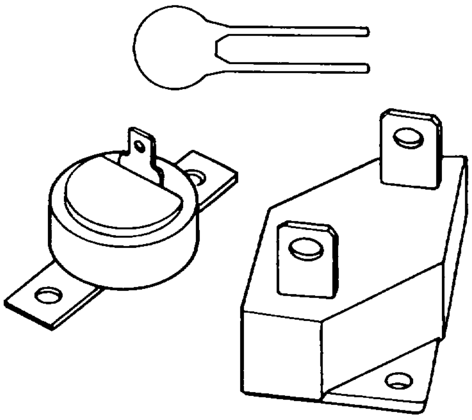
D. SINGLE-GAP GAS-TUBE
ARRESTER



E. TUBULAR VARISTOR
(CONNECTOR PIN VARISTOR)



F. DUAL-GAP (THREE-ELECTRODE)



G. SECONDARY POWER PROTECTORS
(MOVS)

FIGURE 33. Packaging of typical transient suppression devices.

the arc once it is formed, since operational voltages may sustain the arc, which can cause overloads if it is not extinguished. In 60-Hz ac power systems, the current crosses zero over l/120th of a second, and this may be used to extinguish the arc. It is also common to place another device, such as a small resistance in series with the gap, to permit the voltage on the gap to drop to zero when the transient has passed. Characteristics of spark gaps and gas gaps very with the gas used, the geometry of the device, and the amount of radioactive material used. Designed sparkover voltages can vary from 60 volts to 30 kilovolts. The reaction time varies from 5 nanoseconds for high speed gas gaps, to about 0.8 microseconds for spark gaps in air at atmospheric pressure. Peak current- and energy-handling capacity ranges from 20 to 50 kA or greater than 100 joules. Spark gaps are subject to change due to erosion of the electrodes by the current passing through them. They can fail short or open, and tend to do so with only a few operations at full-rated current.

b. Varistors are bulk semiconductor devices. Their resistance varies with magnitude, but not the polarity of the applied voltage. Varistors are made of a polycrystalline material by pressing and heating mixtures containing either silicon carbide (SiC) or oxides of zinc bismuth. Metal-oxide varistors are even more nonlinear than those made with SiC; therefore, they are better at clamping. MOVs tend to have more voltage overshoot and more power absorption than an avalanche diode. When series inductance, due to leads, is kept to a minimum, MOVs have an advantage over a diode in absorbing transient energy because the whole bulk of the device heats uniformly instead of just a small junction area. This means that high energy capacity can be built into these devices at a lower cost per joule than for a diode. Metal oxide varistors are available with varistor voltages from 4 volts to several kilovolts. Peak currents go up to 50 kA and pulse energy goes up to several hundred joules. Higher capacities may be obtained by stacking MOVs in parallel and higher voltage ratings by connecting them in series. Such stacking results in more stable voltage-firing points than the use of wear-prone spark gaps. Metal oxide varistors tend to change their firing point over time, and when stressed by absorption of pulse energy, the varistor voltage tends to drift downward. When stressed by absorbing more that the rated energy, MOVs go into a second breakdown associated with thermal runaway. This second breakdown results in a drastic drop in the varistor voltage, as well as a drop in the energy that it takes to cause the device to fail. MOVs typically have a voltage-dependent capacitance of from This is not a problem for power line or telephone line protection, but is significant when protecting rf lines. The bulk nature of MOV material allows a versatile shape, and several companies offer cable connectors that have MOVs molded around the pins.

c. Fuses, magnetic circuit breakers, and mechanical crowbars act too slowly to provide significant protection from EMP or lighting. They do, however, provide protection from the power system overloads that result when a surge suppressor fails as a short.

5.5.6.7.9 Combination of devices to achieve maximum protection. Practical EMP, EMI, EMC, and lightning protection designs employ a synergistic combination of devices. For example, a shielded equipment room in a communications center may use filters and MOVs on power lines where they enter the shelter, gas gaps on rf and communications lines, a combination of avalanche diodes and gas gaps on data lines, and waveguides oroptical fibers at shield penetrations. An important concept in economically protecting a sensitive device from a high energy pulse is to progressively limit the energy of the pulse. For example, on a communications line, the first limiter is the protector (MOVs or spark gaps) on the line as it enters the facility. This protector removes most of the transient ener~, but there will still be an overshoot voltage on the leading edge of the transient. A filter can be used next to remove transient energy external to the frequency band of interest. An avalanche diode (or hybrid circuit) can then be used near the equipment being protected to eliminate the transient threat. Figure 33 pictorially presents some of the devices available to the design engineer to elimate damaging transients. To select protective devices, it is necessary to know the range of the damage threshold of the equipment being protected as described in 5.5.6.7.3 (see figure 25). Distance from the facility entrance point is also a factor in the progressive transient-reduction method previously described. When selecting a device, it is helpful to know the threat to the facility (or system) by mode of transient propagation. For example, transients that appear across the current-carrying conductors of a power line as shown on figure 34, are referred to as normal or transverse mode. A power-line transient between a current-carrying conductor or earth (ground) is referred to as a common mode. The level of transients computed or measured for the different modes have significant amplitude differences.

5.6 Transformers. Transformers are critical to the DoD communications mission. They permit the matching of equipment power requirements to the power available in the ac distribution system.

5.6.1 General. A transformer is a device that converts alternating voltages and currents from one value to another by electromagnetic induction. The energy is always transferred without a change in frequency and is accomplished with approximately equal power transfer. A step-up transformer receives electrical energy at one voltage and delivers it at a higher voltage. Conversely, a step-down transformer receives energy at one voltage and delivers it at a lower voltage. Transformers are classified by their construction and their usage. Specific guidance for transformers may be found in NEC article 450 and ANSI C57.12.00 1973.

5.6.2 Transformer classifications based on construction. The two classifications based on construction are the conventional and the autotransformer.

5.6.2.1 Conventional power transformer. The conventional power transformer embodies two or more insulated windings on a core of magnetic material surrounded by an insulating medium such as oil or air.

5.6.2.2 Autotransformer. The autotransformer has a single winding which serves both the input and output circuits.

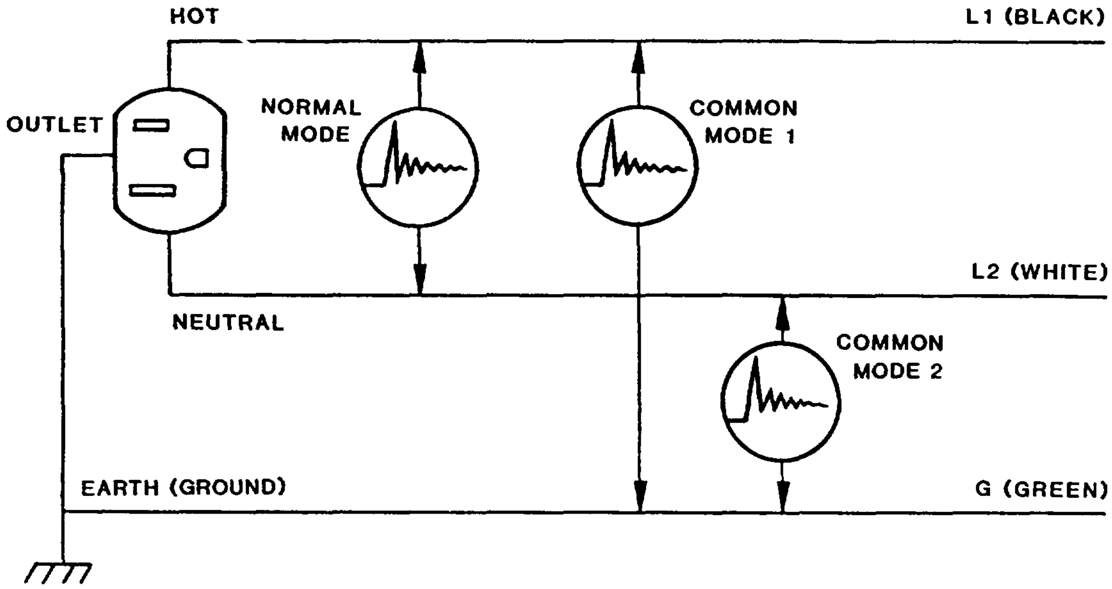


FIGURE 34. Common/normal mode transients in 120 V single-phase power distribution.

5.6.3 Transformer classification based on usage. Transformer classifications based on usage are: distribution transformers, power transformers, and instrument transformers.

5.6.3.1 Distribution transformer. A transformer with a rating of 1500 kVA or less is usually a distribution transformer. Distribution transformers are either liquid filled or dry. Older liquid-filled transformers contained substances that are now considered hazardous materials. These materials must be disposed of as specified in EPA regulations. host new transformers are impregnated with a silicon liquid used as a cooling and insulating medium. Other liquids are also available, and more are being developed to meet the NEC requirements. There are two types of dry transformers: (1) the sealed or closed transformer, and (2) the open or ventilated transformer. Sealed, dry transformers are usually equipped with pressure/vacuum gauges to compare readings with manufacturer’s recommendations and with previous readings.

5.6.3.2 Power transformers. Power transformers usually cover the range from 15 kVA to 1500 kVA. They come in both liquid and dry types.

5.6.3.3. Instrument transformer. Instrument transformers are designed to transform either current (amperage) or potential (voltage) for use in measurement, control, or protective device operation. Instrument v transformers are of two types - (1) potential transformers, and (2) current transformers. The major difference between these two transformers is the method of connection to the power system. Current transformers are also available that surround the conductor, but are not physically connected to the circuit.

5.6.4 Transformer vaults. Any space under cover used to house distribution transformers, switches, or other electrical equipment can be classified as a vault. Since each vault is built to meet a special load condition, only general guidance is provided. More information on transformer vaults may be found in the NEC.

5.6.4.1. Interior vaults. Vaults constructed within a building must be fireproof, unless nonflammable liquid is used in the transformers and other equipment. In order to confine any liquids escaping from a transformer or other electrical equipment, the vault should have at least a six-inch ridge around all sides. The door sill should also be at least six inches above the floor. The vault should be equipped with a drain. If flooding is possible, and a gravity drain cannot be provided, an automatic sump pump should be installed.

5.6.4.2 Ventilation. Proper ventilation in a transformer vault is necessary to prevent excessive heating of the transformers. Natural or forced air must be provided. Normally, three square inches of natural ventilation is provided for each kVA of installed capability. If forced air is used, the volume of air needed is normally 100 cfm per kW of transformer capacity.

5.6.5 Transformer connections. There are many combinations for connecting transformers. his handbook will only discuss the most common three-phase connections, which are delta-delta, delta-wye, and wye-wye connections.

5.6.5.1 Delta-delta. The delta-delta, three-phase, three-wire connection may be used to supply a balanced three-phase load. All transformers should be the same size and have similar characteristics. For balanced systems, the line current equals the square root of three times the transformer phase current. The kVA capacity of each transformer in the bank should be 0.58 EI (kVA), where E is the phase-to-phase voltage, and I is the line current. For three-phase and single-phase load requirements, the secondary winding of one of the transformers can be tapped to provide the single-phase load.

> NOTE: In the case of a corner-grounded delta, taps to provide lighting and wall-outlet power must be made on one of the phases that shares the corner ground point to avoid the dangerous high voltage present on the remaining phase. Since single-phase load is not distributed equally between phases, the transformer supplying the single-phase load is normally larger to prevent an overload condition. This configuration is seldom employed on transformers at DoD facilities.

5.6.5.2 Delta-wye. In a delta-wye connection, the primary windings are connected in delta, and the secondary windings are wye connected. A combined three-phase power and single-phase lighting load may be supplied from this connection. An advantage of this connection is that single-phase loads can be equally divided among all three transformer phases. The phase-to-phase voltage in the wye connection is equal to the square root of three times the phase-to-neutral voltage. This configuration is the most preferred type employed at Doll facilities.

5.6.5.3 Wye-wye. In the wye-wye connection, both the primary and secondary windings are wye connection. This connection is used under the same conditions as the delta-wye connection to supply mixed distribution loads. It is important when making this connection to ensure that the primary and secondary neutrals are connected to the primary line neutral.

5.6.5.4 Polarity. Transformer polarity refers to the relative direction (left-to-right, or right-to-left) in which the primary and secondary windings are wound about the core. The leads are marked accordingly. Transformer polarity is either additive or subtractive, and is stamped on the nameplate. Polarity is important only when transformers of different polarities are connected in parallel, or are used to supply three-phase service. transformers are of the same polarity, it is immaterial whether they are additive or subtractive. In the United States, additive polarity is standard for all single-phase distribution transformers of 200 kVA and below that have high-voltage ratings of 7,500 volts and below. Other single-phase distribution transformers have subtractive polarity. When connecting single-phase transformers for a three-phase system, the leads of the transformers must all be connected the same. Transformers with opposing polarity will burn up. To reduce the effects of harmonics on connected equipment, it is preferable to select three-phase transformers that share a common core structure as opposed to using three, single-phase units.

5.6.6 Loading of transformers. It is extremely important that transformers be properly loaded for the following reasons.

5.6.6.1 Underload. While the transformers themselves may not be damaged, lightly loaded or unloaded transformers introduce inductive reactance and a lagging power factor into the power system which wastes power. For optimum efficiency, and to prevent introducing a lagging power factor into the supply line, transformers should be operated at three-fourths to full load. If service conditions require that partially loaded inductive equipment remain connected, capacitive loads should be provided as a balance.

5.6.6.2 Overload. Transformers should not be overloaded without a thorough knowledge of the limitations involved. Among the limitations are: lead-wire size, soldered connections, tap-changers, oil expansion (causing pressure increases) in sealed-type units and bushings, and the thermal capability of control equipment and associated circuit-breakers, fuses, reactors, disconnect switches, current transformers, alarms, and line wires. Any of these components can be damaged if the transformer is operated for a very long period in the overload condition. Normally, if the overload is intermittent and not continuous for more than two hours, distribution transformers may be loaded to 150 percent of the nameplate rating, provided the practical limitations of the protective devices are observed. The transformer should be allowed a cooling period of at least one hour before the transformer is overloaded again. Four-hour overloading should not exceed 125 percent of the nameplate rating. Requirements for overload capabilities of transformers are indicated in ANSI C57.91 and ANSI 57.92.

5.7 Low-voltage ac distribution. The distribution of low-voltage ac power within the facility should be designed so that each needed service operates without interference or disruption to any other service. This distribution should be free of anomalies and abnormalities that would cause loss of equipment synchronization, discontinuity of electronic switching functions, or physical damage to the equipment. The data collected as part of the site survey and mission requirements analysis (see Volume I) is used to define the load centers required and to plan the distribution. Normally, two distributions are required -- technical power and nontechnical power.

5.7.1 Technical power hierarchy. Technical power is the distribution that provides the energy needed for the mission. It may also include supporting functions, such as air conditioning and lighting which are essential-to the operation of the equipment. Technical loads are further divided into two subcategories (see figure 35) - critical technical load, and noncritical technical load.

5.7.1.1 Critical technical load. Critical technical load is principally associated with systems having a requirement of 100-percent continuity in power service, such as command, control, communications, and information (C^3I) facilities. Such systems normally require on-line uninterruptable power systems (UPS). Systems that would require extensive reprocessing due to loss of data during a power failure might also qualify as critical technical electronic load. These loads must not be shed intentionally, if sufficient power is available to supply them.

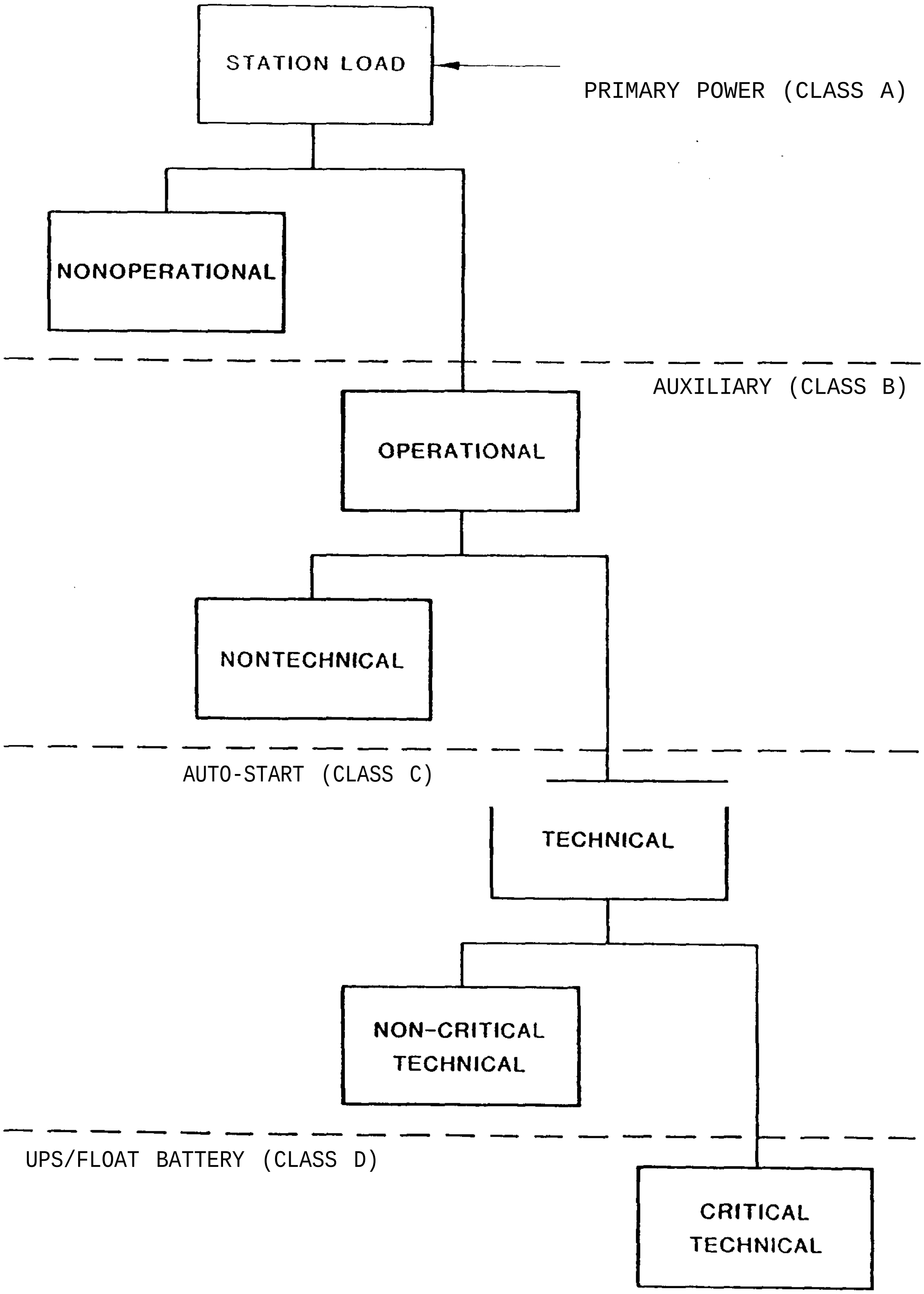


FIGURE 35. Power hierarchy diagram.

5.7.1.2. Noncritical technical load. Noncritical technical load is that portion of the technical load that directly supports the routine accomplishment of facility missions. This load includes general lighting and power systems, HVAC, and similar equipment that can tolerate brief power outages without loss of data or without an adverse effect on mission accomplishment. Backup power for this load category would normally be an automatic-start, automatic-transfer engine generator. In some cases, an off-line UPS will be specified for power restoration.

5.7.1.3 Nontechnical load. The nontechnical load does not directly support the mission and an extended power loss will not adversely affect the mission. These loads are to be shed first and restored last during power shortages and restoration. These systems can be backed up by alternate commercial feeds and on-site engine generators.

5.7.2 Nonoperational load restoration. Restoration for a nonoperational load may range from waiting for commercial power to be restored to use of automatic-start, manual-transfer (or manual start) engine generators.

5.7.3 Load distribution design. Figure 36 is a one-line drawing of a facility requiring all categories of power. The system depicted is a spot-network system in which secondary nominal service is 480/277 V, with 208/120 V being provided by substation transformers. Three basic types of distribution systems may be employed in a facility: (1) radial, (2) primary selective, and (3) secondary selective.

5.7.3.1 Radial distribution. If power to the facility is nominal utilization voltage, then the radial distribution is most often applied. A radial system is characterized by a single incoming supply circuit. Then the power is distributed around the building. In some instances, a medium-voltage supply may be brought into a transformer on the premises that steps down to utilization voltage. Figure 37a depicts typical radial circuit arrangements. The radial system has one serious drawback - an outage of the single source affects the whole facility.

5.7.3.2 Primary-selective distribution. Primary-selective distribution eliminates the maJor shortfall of the radial distribution by bringing two primary feeds to the facility. The secondary feeds are equipped with switchgear to connect the loads to either incoming primary feed. depicts typical primary-selective arrangements.

5.7.3.3 Secondary-selective distribution. The secondary-selective distribution is a modification of the radial distribution. Two primary feeders are brought into the building to two or more secondary feeders: The secondary radials include tie breakers that enable the secondaries to be tied to one feed in case of a failure of the second. The secondary feeders and breakers are typically rated to carry the total load, but they may include interlocks and load-shedding mechanisms to minimize critical loads in emergency situations. Figure 37c depicts the secondary-selective distribution.

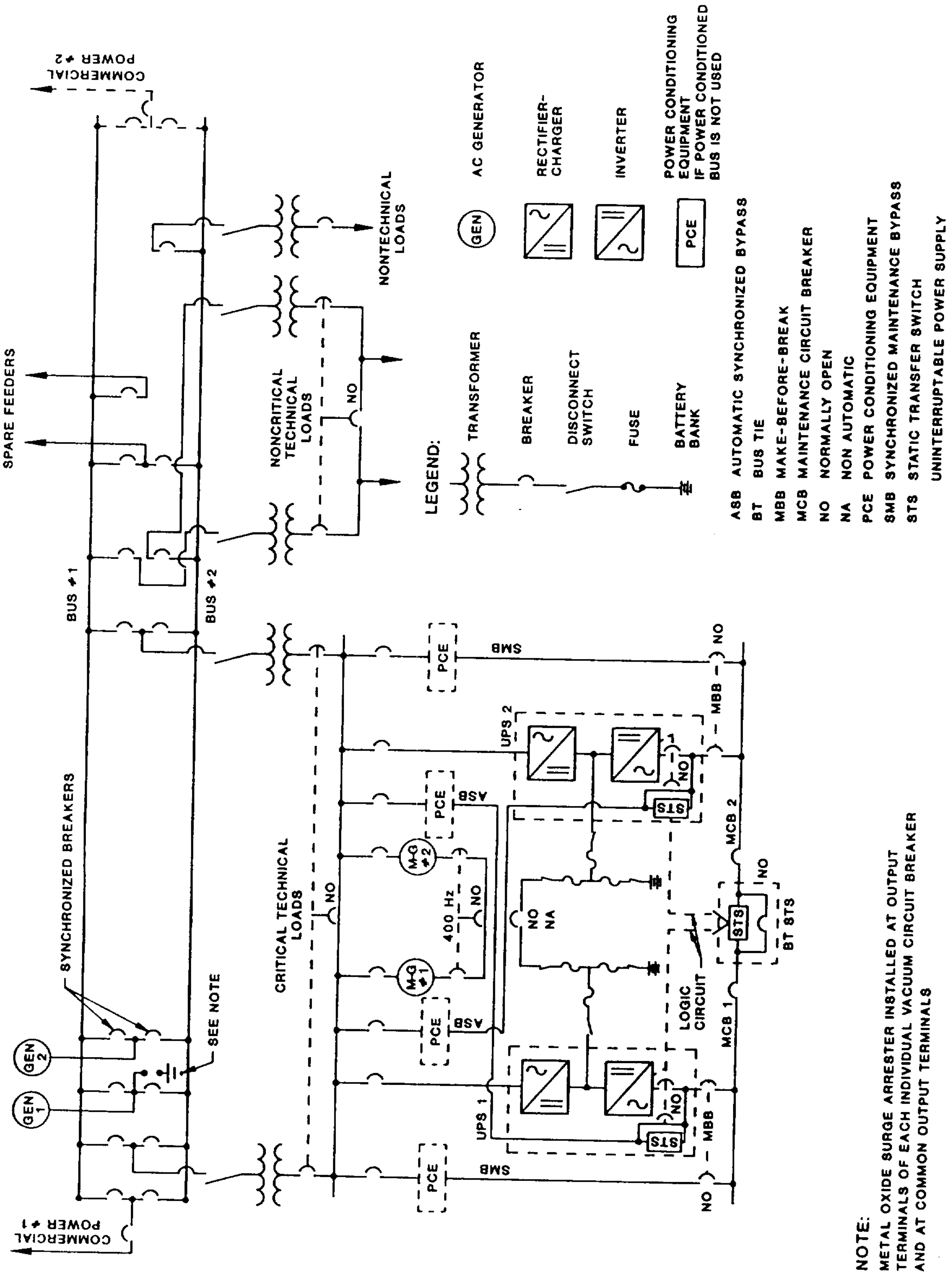
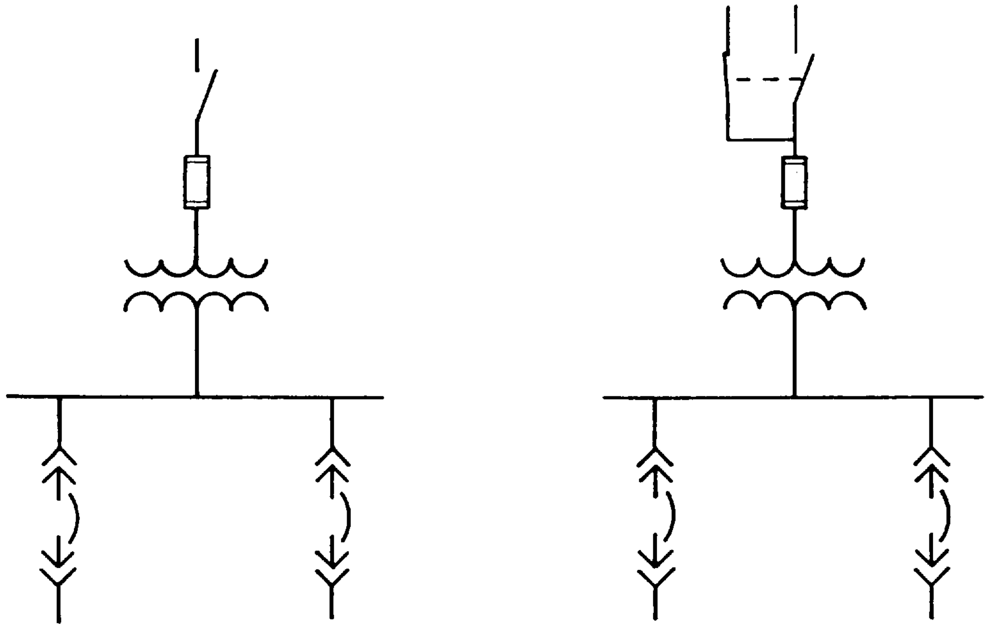
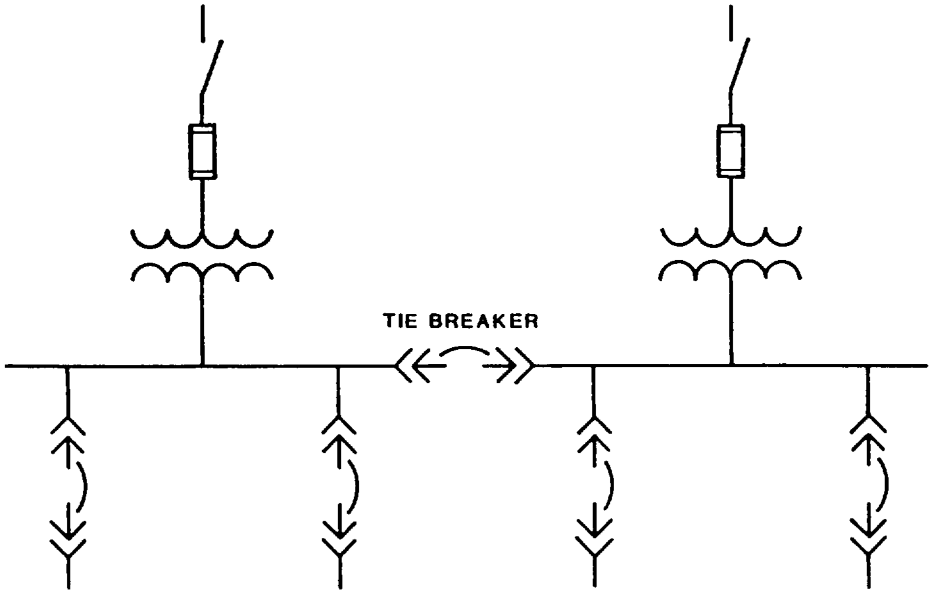


FIGURE 36. One-line diagram of a facility requiring all categories of power.



A. SIMPLE RADIAL SYSTEM

B. PRIMARY SELECTIVE SYSTEM



C. SECONDARY SELECTIVE SYSTEM

FIGURE 37. Commonly used primary distribution systems.

5.7.4 Distribution system components. The facility power distribution system consists of the following components:

a. Primary unit substations.
b. Secondary unit substations.
c. Panelboards.

5.7.4.1 Primary unit substation. Primary unit substations come in many configurations depending upon the preference of the local utility. All configurations perform the same function - to reduce the high or medium voltage on the transmission lines to above 1000 volts, and to provide protection to lower-voltage feeders from disturbances on the transmission grid. Typically, these substations step 13.2 kV or 13.8 kV to 4160 V or 2400 V service. Such substations are combinations of transformers and power interrupter switchgear or power circuit-breaker switchgear. NEMA 201-1970 provides standards for primary unit substations.

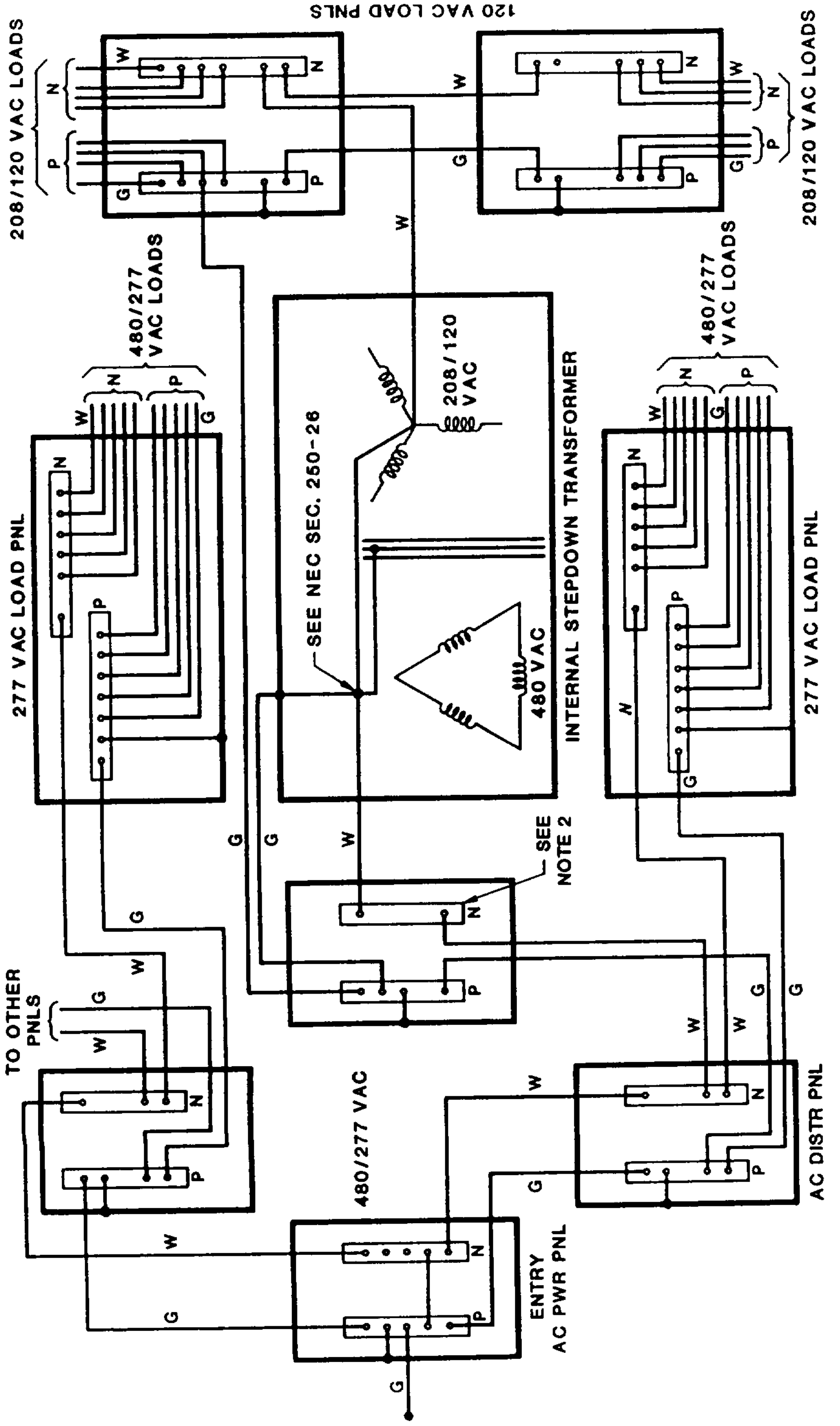
5.7.4.2 Secondary unit substations. Secondary unit substations are that portion of a distribution system usually located on a user’s premises. purpose of the secondary unit substations is to reduce the voltage from the primary unit substations to levels of 600 volts or less. These substations also provide protection to low-voltage sections from disturbances and faults ocurring in the primary unit substations. Secondary unit substations consist of incoming lines, transformers, and low-voltage sections. Standards for secondary unit substations are contained in NEMA 210-1970.

5.7.4.3 Panelboards are used to provide protective and disconnect devices for each low-voltage distribution line in the facility. Two types of panelboards are employed in a facility: power distribution panels, and lighting and appliance panels.

Specifications for these panelboards are contained in NEMA PB1. Instructions for installation of panelboards are contained in NEMA PB1-1.

5.7.4.3.1 Power distribution panels. For this handbook, power distribution panels provide service entrance disconnect and further distribute protected power to the lighting and appliance panels. For those panels used for service entrance disconnect, the neutral- (grounded conductor-) bus bar must be provided with a means to connect an appropriately sized grounding conductor to establish the (green wire) fault protection subsystem as shown in figure 38.

5.7.4.3.2 Lighting and appliance panels. These panels are used throughout the building to provide protection and disconnect means for the individual branch circuits. Panels used for lighting and appliances must be constructed with the neutral- (grounded conductor-) bus bar isolated from the enclosure. Further, the neutral bus bar must not be bonded to the green wire fault-protection-subsystem bus bar (grounding conductor). (Note: The term "appliance", as used here, applies to any low-voltage branch circuit requiring 30 amperes or less.)



N AC NEUTRAL BUS
P FAULT PROTECTIVE BUS
W WHITE (NEUTRAL CONDUCTOR)
G GREEN (PROTECTIVE CONDUCTOR)

NOTES:

1. FOR CLARITY, 3-PHASE WIRES, FUSES, SWITCHES, AND CIRCUIT BREAKERS ARE NOT SHOWN
2. FOR SEPARATELY DERIVED SYSTEMS (NEC SECTION 250-26) THE NEUTRAL WILL BE CONNECTED TO GROUND AT A POINT NEAR THE INTERNAL STEPDOWN TRANSFORMER

FIGURE 38. Grounding and neutral (grounded) wiring.

5.7.5 Power distribution design. The design of the power system begins with determining what power scheme is available from the supporting utility company and how best to interconnect with it. That information then determines the secondary scheme. The internal low-voltage design is at the discretion of the project engineer. This handbook provides guidance on preferred distribution methods.

5.7.5.1 Primary unit substation. The facility designer will probably have little control over the primary unit substation. However, he must be aware of the configurations that can be offered by utility companies. Whenever possible, the designer should insist on dual primary feeds from separate sources. These separate sources are needed as input to the secondary networks for improved continuity of operation and reduced probability of disruption. Regardless of the number of primary feeds, each primary unit substation consists of the same components -- a transformer, and service interrupter/switchgear.

5.7.5.1.1 Transformers. In general, the transformer in the primary unit substation will step down a transmission voltage in a range of 2.4 - 69 kV to a level of no more than 600 V to feed the secondary unit substation. Depending on the load requirements of the facility, the primary unit transformer will probably be located outside on a pad. The following criteria should be considered in sizing and selecting a transformer:

a. Kilovoltampere (kVA) rating.

b. Voltage rating, ratio, and method of connection.

c. Voltage taps and method of tap change.

d. Impedance value.

e. Type of cooling and temperature rise.

5.7.5.1.1.1 Kilovoltampere (kVA) rating. The kilovoltampere rating of the required transformer is determined from the total ampere eauipment requirement as noted in the site survey. The figure used is the current rating of the equipment, or the power rating, adjusted by the power factor. For instance, if equipment power ratings are 800 watts with a power factor of 0.80, the kilovoltampere requirement is 1 kVA plus an overload margin of 25 percent. Transformer capacities are becoming standardized, and are cited in ANSI/IEEE C57.12.00.

5.7.5.1.1.2 Voltage rating, ratio, and taps. The input voltage rating must match that provided by the utility company. The higher the primary voltage, the less likely are voltage/current fluctuations. The secondary ratio is variable depending upon the design and layout of the facility. Distribution voltage may be at level of 600 V or less. The primary side of primary unit substations is typically configured as delta. The secondary connection depends upon user requirements. If the secondary voltage is at utilization voltage, the wye connection is preferred due to less problems with harmonics than with delta.

5.7.5.1.1.3 Voltage taps and method of tap change. The primary side of the transformer should be equipped with step-up and step-down taps to vary the primary-secondary ratio in the event of voltage drops or rises. Each tap should accommodate a 2.5-percent change with a minimum of two taps up and two taps down.

5.7.5.1.1.4 Transformer impedance. The internal impedance of any power source will have an effect on the voltage at the load when the source reaches its rated capacity. For instance, a transformer providing 120 V at 100 kVA will present 114 volts to the load at capacity. Since acceptable voltage drop at the load is 5 percent, including drops for distance, switches, etc., a 5-percent impedance source is the maximum acceptable. Thus, it is important to have transformers with as low internal impedance as practical (3 to 5 percent). The rating is considered at worst-case condition with a power factor at zero and with current lagging. Increasing the capacity of the transformer proportionally decreases the voltage drop at the current of interest. Where the power factor approaches unity, the voltage drop becomes insignificant. For a typical facility with a power factor of 0.80, the voltage drop in a 5-percent power source is 1 percent. Allowable impedances for transformers are defined in ANSI/IEEE C57.12.00. The allowable impedances are a function of application, output voltage, and rated kVA.

5.7.5.1.1.5 Types of cooling. Transformers require some type of cooling mechanism to carry away generated heat. The mechanism is determined by the manufacturer. Some transformers are oil cooled, some are forced-air cooled, some are convection cooled. The type of cooling will determine the installation criteria. Oil-filled transformers are usually inappropriate for indoor installation. Forced-air cooled units will require ducting to vent heated air. Convection cooling may add an unacceptable burden to the space conditioning. Specific guidance for transformer location and cooling is contained in NFPA 70 Article 450.

5.7.5.1.2 Interrupters, switchgear, and protectors. The primary unit substation is equipped with mechanisms that allow Interruption of service in the event of overload, provide an ability to add or subtract loads or reconfigure the network, and offer protection to the load from disturbances in the grid and to the grid from faults in the load. Components include current-limiting fuses, interrupting switchgear, control devices, and auxiliary equipment. Devices may be manually or automatically controlled. Circuit breakers may be incorporated into the switchgear to provide protection in lieu of fuses. Controls are needed to open and close switchgear for continuity of operation in the event of failure.

5.7.5.2 Secondary unit substation. The secondary unit substation is similar in function and configuration to the primary unit substation. The significant differences are in the current ratings and voltage levels. current ratings are typically 125 percent of rated loads. Voltage ratings are either 480Y/277 V, or 208Y/120 V. Transformers are configured as wye connections rather than delta. Voltage taps on the transformer are on the secondary side versus the primary side.

5.7.5.3 Panelboards. Panelboards are the last element of the distribution system before connection to the equipment and systems of the facility. Panelboards contain fuses or circuit breakers for each energized line feeding, or being fed, by the panelboards. Provision is also included for a consolidated neutral bus and fault-protection subsystem bus. Since 3-phase/five-wire power with fault-protection (green-wire) subsystem wiring is preferred, all panel boards should be three-phase.

5.7.5.3.1 Panelboard locations. Panelboards are located throughout the facility near the loads. Because of the inherent voltage drops in the feeders and branch circuits, the total distance from the secondary unit substation transformer through the panelboard to the load should not exceed 200 feet. For instance, a 100-ampere panel, using 4 AWG feeders, drops 2.6 volts at full-rated current at 100 feet. A 20-ampere branch circuit on 12 AMG wire from that panelboard drops 3.24 volts at rated current at 100 feet. Per ANSI C&34.1, the minimum acceptable voltage on a 120-V branch is 114 V. This example, which does not account for resistance at connectors, services, or switches, nor loss due to power source impedance, is marginal at 114.16 V. Thus, such distance should be less than 200 feet. While one could argue that an increase in conductor size would increase the permissible distance, because the cost of copper is high, it is usually cheaper to locate panelboards and secondary unit substations closer to the load. Where foreign wire sizes are the only ones available, the next larger wire size in circular mills will be specified.

5.7.5.3.2 Panelboard load assignments. Load assignments to panelboards must follow the power categories defined in paragraph 5.7.1. Next, after the load assignment, is an assessment of the specific loads and effect of these loads on other equipment assigned to the panelboard. At least one panelboard is required for each type of load defined in 5.7.1. In addition, within a particular category, any inherent transient-producing load, such as high torque, short-cycle motors, should be powered from separate panelboards away from solid-state mission equipment. Where multiple missions exist in multiple rooms in a facility, continue to divide panel boards in each room into separate load centers for each type of power required. Where classified information is processed, see MIL-HDBK-232 for further discussion on separate panelboard requirements.

5.8 Direct current (de) power systems. Various types of electronic equipment require dc voltage. Use of dc volta e serves two purposes - (1) highly regulated power may be provided, and (2) emergency backup power may be incorporated into the system. DC voltage may be provided by a system which uses devices such as rectifier chargers, wet-cell storage batteries, de-to-de converters, ac-to-dc converters, or dc-to-ac inverters. Various devices are used depending on the dc voltage requirements of the facility.

5.8.1 Types of dc power supplies. The power supply which converts ac voltage to dc voltage should perform several important functions: (1) voltage transformation (changing the ac line voltage through rectification to another more suitable voltage), (2) filtering (smoothing the ripple voltage of the converted or rectified voltage), (3) regulation (controlling the output voltage to give a constant value with line, load, and temperature changes), and (4) isolation (i.e., electrical ly separating the input and output voltages). The ideal power supply characteristics are: (1) constant output voltage regardless of variations in line voltage (i .e. , input), load current, and ambient temperature, (2) zero output impedance at all frequencies, (3) 100-percent efficiency, and (4) no ripple or noise on output voltage. There are two types of dc power supplies - switching and linear. Each type has its own advantages and disadvantages. The advantages of switching power supplies are: high efficiency (60-80 percent), high power density, and wider input voltage range than linear supplies. The disadvantages are poor line and load regulation, and high output voltage ripple. Poor line and load regulation may be improved by using linear post regulators. Advantages of linear power supplies are precise line and load regulation, and good output ripple-voltage suppression. The disadvantages are: low transformer efficiency at the input, significant voltage loss across rectifier diodes at the output (during conduction of the capacitor-charging pulses), and the fact that the linear regulator is a dissipative circuit that has a minimum permissible voltage drop across the series-pass transistor. This drop is determined at minimum line voltage, and therefore, is higher at nominal or high line voltage. All these losses result in an output efficiency of approximately 45 percent at a 5-volt output. In addition, operating temperature for dc power supplies should be specified in ambient temperature, not case temperature. Sufficient space for air flow (for cooling) must be provided when units are installed. One of the following methods of cooling should be applied if high ambient temperatures are anticipated: (1) forced-air cooling, (2) heat sinking to metal chassis, (3) using a heat sink with fins, or (4) operating at derated output. The last method may result in some loss of efficiency and should be avoided whenever possible. Deratinq may also result in deceased mean-time-between-failures” (MTBF).

5.8.1.1 Rectifier chargers. Rectifier chargers are used to convert the supplied ac voltage to dc voltage and maintain a constant level of charge in storage batteries; This device may be used in two basic configurations - (1) it may be connected to a bank of storage batteries with the batteries connected to the de-voltage bus, or (2) the rectifier may be connected to the de-voltage bus to provide power to the dc load with the charger connected to the battery bank to maintain a constant level of charge. When the second configuration is used, the batteries may be automatically switched to the dc bus to provide power during power outages. Rectifier chargers should be of solid-state design. The most commonly used units employ silicon-controlled rectifiers (SCRs or power transistors for rectification. Disk-type rectifiers (copper oxide or selenium) may also be used. Although disk rectifiers will withstand higher operating temperatures than SCRs, they should only be used where high temperatures are unavoidable. Failure of a disk rectifier may result in the emission of poisonous gases. Rectifier chargers using SCRsS are highly stable devices and provide the best regulation of all available devices. The SCR is a four-layered, three-terminal semiconductor device which consists of an anode, cathode, and gate. The SCR shows an open circuit until a low-power signal applied between the gate and cathode provides a highly stable voltage level at the anode. The schematic representation of an SCR is shown in figure 39. Units using power transistors may be used; however, regulation is not as effective as that of SCRs. When calculating rectifier-charger capacity, the required ampere-hours, recharge time, temperature, and altitude factors must be known. The following formula is used to determine needed capacity in amperes:

$$\text{Amperes} = \frac{\text{Ah X 1.1}}{\text{T}} + (\text{L/kl})\ (\text{L/k2})$$

where: Ah = ampere-hours removed from the battery during use.

T = desired recharge time.

L = continuous load during recharge.

k1 = temperature factors (provided by the battery manufacturer to adjust for extremes in temperatures; normally not affected by temperatures below 100 °F. T

k2 = altitude factor (provided by the battery manufacturer to adjust for high altitudes). Typical examples of k2 are:

ALTITUDE (feet)	FACTOR
5,000 - 10,000	0.80
3,300 - 5,000	0.95
0 - 3,300	1.00

5.8.1.2 Converters. There are two types of converters used - (1) ac-to-dc converters, and (2) de-to-de converters. The ac-to-dc converter changes the supplied ac voltage to dc voltage through the same process as the rectifier-charger; Converters differ from rectifier chargers because they are only used to supply dc voltage to the load equipment. Converters are not usually used for charging batteries. The simplest ac-to-dc converter is the half-wave rectifier shown in figure 40. Due to the excessive ripple voltage, this device should only be used for low-voltage, low-current applications where precise regulation is not required. Most DoD applications will require highly efficient dc voltage; therefore, full-wave bridge rectifiers as shown in figure 41 should be used. Due to the additional rectification and filtering, it is recommended that converters requiring three-phase power and employing SCRs for regulation are used to provide highly stable, low ripple dc voltage. De-to-de converters are used to provide dc voltages other than that provided by the primary de-voltage source. This is done by converting the supplied dc voltage to a square-wave ac voltage. Then ac voltage is converted to dc voltage again. Since a square-wave ac voltage is used, rectification and filtering will produce highly stable dc voltage with extremely low dc ripple voltage.

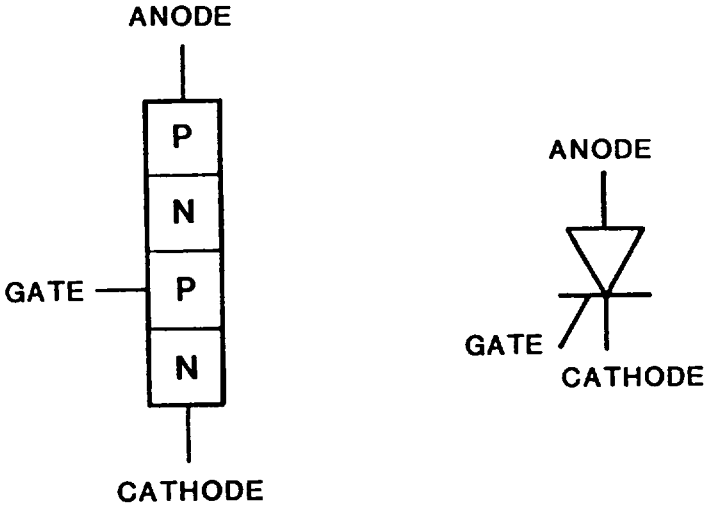


FIGURE 39. Schematic representation of an SCR.

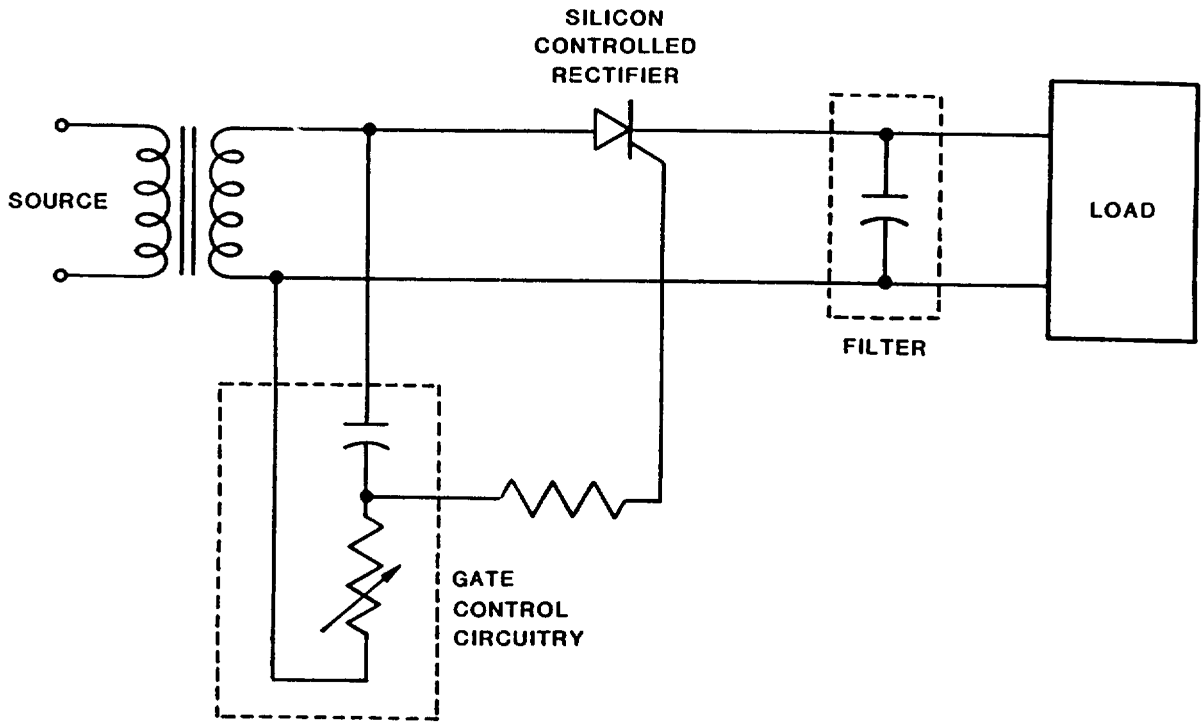
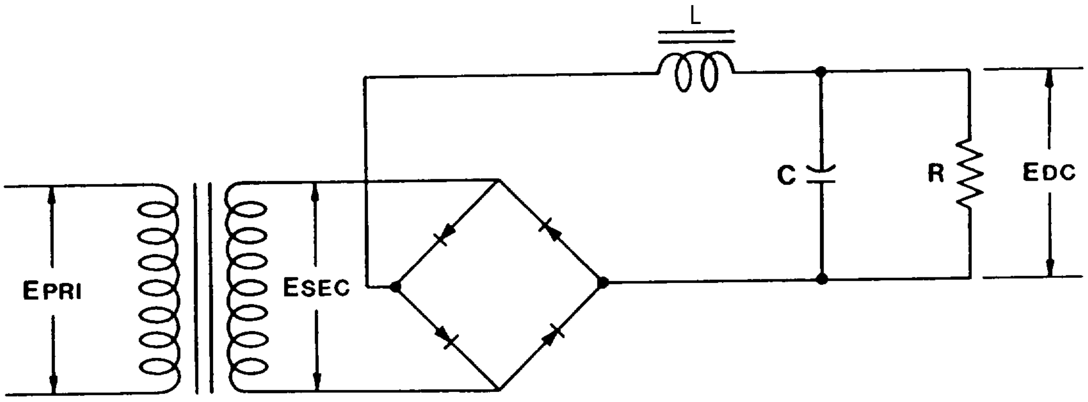


FIGURE 40. Half-wave rectifier.



FULL WAVE BRIDGE RECTIFIER

FIGURE 41. Full-wave bridge rectifier.

5.8.1.3 Inverters. Inverters are used to change the applied dc voltage to ac voltage. The basic function of the inverter is to provide ac power to equipment when there are primary ac power disturbances. The dc voltage applied to the input of the inverter is converted to ac voltage by a solid-state electronic switching matrix that produces a square wave. Since most equipment used would require a sinusoidal wave, the output voltage waveform must be modified. Various second- and third-order harmonic filters may be used; however, these filters tend to be large, costly, and highly load dependent. To avoid this, it is desirable to use an inverter that is designed to have no low-order harmonics. Higher-order harmonics can then be filtered, producing a nearly sinusoidal output waveform. Methods of producing such a waveform from a square-wave inverter are harmonic neutralization and pulse-width modulation. A harmonic neutralized inverter consists of multiple square-wave inverter stages that are phase-shifted by 180 degrees. For a polyphase ac output, each inverter stage contributes to the output of each phase by a process of phase addition accomplished through transformer windings. The resultant output is a stepped sine wave, virtually devoid of harmonic frequencies. When using a polyphase inverter, it is essential to balance the load between all phases to reduce the possibility of equipment-generated power disturbances. Pulse-width modulation inverters produce sine-wave outputs by switching the applied dc voltage at a rate higher than the fundamental frequency. The device also contains a frequency converter to produce the desired output frequency.

5.8.1.4 Dc power supply phases. Dc power supplies are available with single-phase or three-phase inputs. Single-phase units may be used for low voltage applications (24 Vdc or less); however, three-phase units are more effective at higher voltages. A three-phase power supply conducts for 120 degrees of the cycle, producing a harmonic ripple frequency that is six times the frequency of the ac source. The resultant effect is a much lower ripple voltage. This lower ripple voltage provides more stable dc voltage to the load. Table XVII provides input/output characteristics of single-phase dc power supplies. Table XVIII provides input/output characteristics of single-phase and three-phase dc power supplies.

5.8.2 DC voltage distribution. The efficiency of the dc voltage system depends on the distribution system, as well as on the equipment. Use of the appropriate size wire, minimal loss, load balancing, and adequate grounding are all contributing factors to a highly efficient system.

5.8.2.1 Protection devices. It is essential that adequate protection is provided for dc power sources and loads. This protection must be designed to protect sources and loads from surges on the line side of the equipment, and from overload conditions on the load side. Protection should be provided for power distrubances such as lighting and EMP. Devices used to provide dc voltage should be fuse protected on the input and output by the manufacturer. It is recommended that additional protection be provided by installing circuit breakers or fuse panels near the dc source equipment. If rectifier chargers are mounted in racks or cabinets, the panels may be installed in the same enclosure. In battery facilities, fuses should be installed between the rectifier charger and battery bank, and between the battery bank and the load equipment. Fuse panels protecting the load equipment should be installed close to the load equipment to provide easy access and to enhance dc power distribution.

TABLE XVII. Input/output characteristics of single-phase dc power supplies.

Ac input voltage range	Ac input current range (amps)	Frequency Hz	Dc output voltage	Dc output current range (amps)
115-550	3-20	50/60		3-100
115-550	3-20	50/60	12	3-100
115-550	4-24	50/60	24	3-75
115-550	4-30	50/60	36	3-75
115-550	4-50	50/60	48	3-75
115-550	7-60	50/60	120	3-75
115-550	8-60	50/60	240	3-25

TABLE XVIII. Input/output characteristics of three-phase dc power supplies.

Ac input voltage range	Ac input current range (amps)	Frequency Hz	Dc output voltage	Dc output current range (amps)
208-550	4-65	50/60	24	25-800
208-550	6-75	50/60	36	75-400
208-550	8-90	50/60	48	25-800
208-550	11-120	50/60	120	16-600
208-550	25-65	50/60	240	20-300

5.8.2.2 Dc conductors. All dc voltage lines should be continuous runs since splices may add undesirable resistance and cause an unacceptable voltage drop. If lines must be tapped to provide parallel circuits to various equipment, crimp-type insulated "T" connectors should be used on stranded Wire (No. 12 AWG) above. Care must be taken to ensure a tight bond between the wire and connector. De-voltage lines should not be installed in the same conduit or duct as ac voltage or signal lines, as undesirable noise may be induced through electromagnetic coupling. When multiple de-voltage sources are used, load balancing becomes important. Proper distribution and balancing will aid in providing stable power, since de-power sources provide maximum efficiency when operated near their peak loads. It is recommended that, for this reason, de-power sources be loaded to approximately 80 percent of their maximum loads. A typical dc distribution network is shown in figure 42.

5.8.2.3 Batteries. Wet-cell storage batteries are common elements of dc voltage systems. Each battery is made up of one or more cells consisting of a positive plate, negative plate, and an electrolyte solution. There are three basic types of wet-cell storage batteries used: (1) lead/antimony, (2) lead/calcium, and (3) nickel/cadmium. Cells are connected in series to provide the desired voltage, with each cell producing approximately 2 volts for lead/antimony and lead/calcium cells, and approximately 1.2 volts for nickel/cadmium cells.

a. A wet-cell battery converts chemical energy contained in the active materials into electrical energy by means of an oxidation-reduction electromechanical reaction. This reaction causes a transfer of electrons from one conductive element to another conductive element. As shown in figure 43, the negative electrode or anode gives up electrons being oxidized during the process. The anode is separated from the cathode, which is the positive plate and the oxidizing material. The cathode accepts the electrons given up by the anode. This transfer of electrons takes place through an external load which connects to two electrodes, providing a resistive path, and then through the electrolyte solution to complete the circuit.

b. When an external load is connected across cell terminals, current flows as a result of the difference in potential between the negative and positive plates. As current flows in the external load, chemical changes take place within the cell. The sulphuric acid (H_2SO_4) in the electrolyte combines with lead oxide (PbO_2) from the positive plate to form lead sulphate ($PbSO_4$) and water (H_2O). The acid also combines with pure lead (Pb) from the negative plate to form lead sulphate and water. As the discharge continues, the electrolyte gives up more acid and the lead sulphate penetrates deeper into the plates. At the low-voltage cutoff point, the cell has discharged from 2 volts to approximately 1.75 volts. Due to the internal resistance of a cell, a battery rarely has an open circuit. This creates the tendancy for the battery to discharge itself even without an external load connected to the plates. This discharge, or local action loss, is low at the start of cell life, but increases with time, due to plate deterioration. The rate of local action loss is greater in lead/antimony cells than in lead/calcium cells, since calcium is harder and more durable than antimony. A description of the types of lead-acid batteries is contained in 5.8.2.3.5.

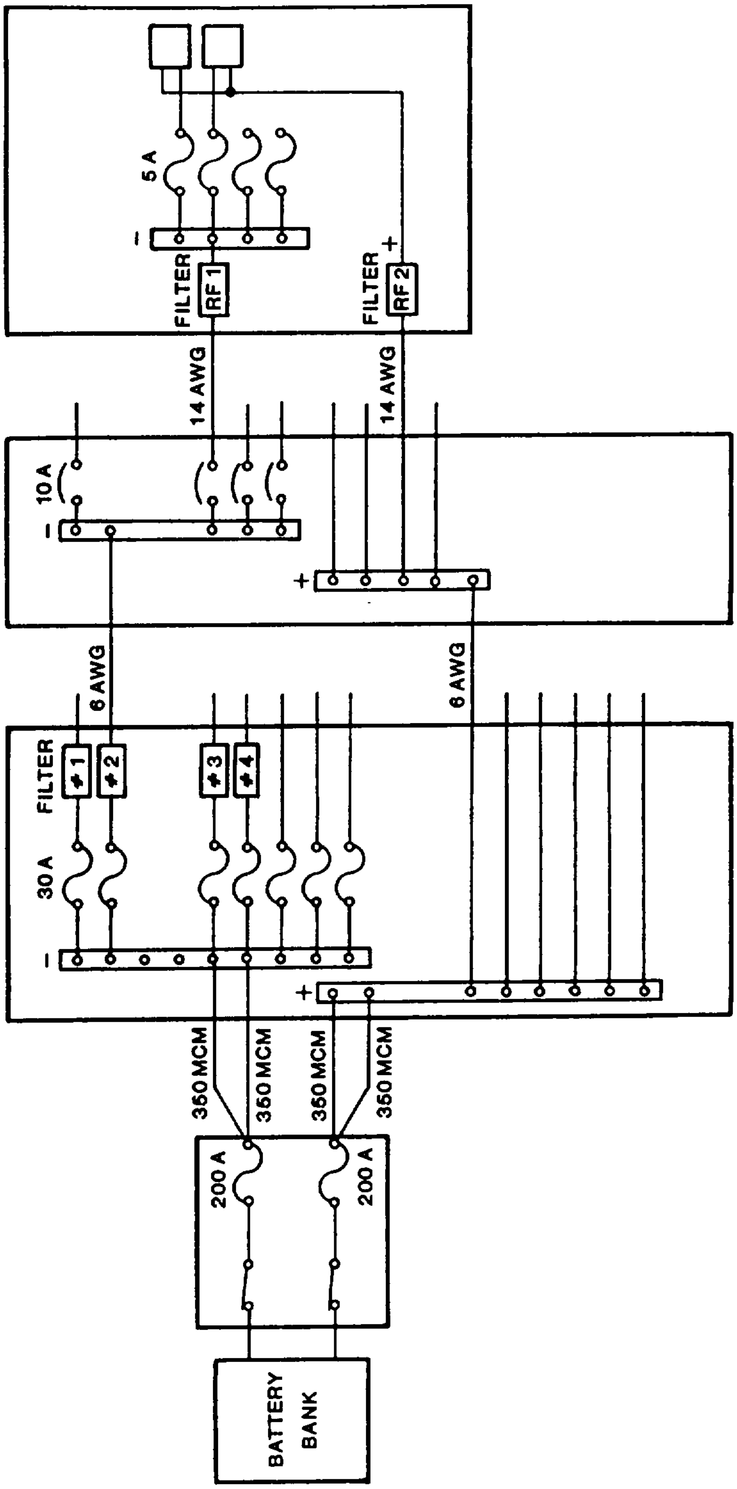


FIGURE 42. Typical dc distribution network

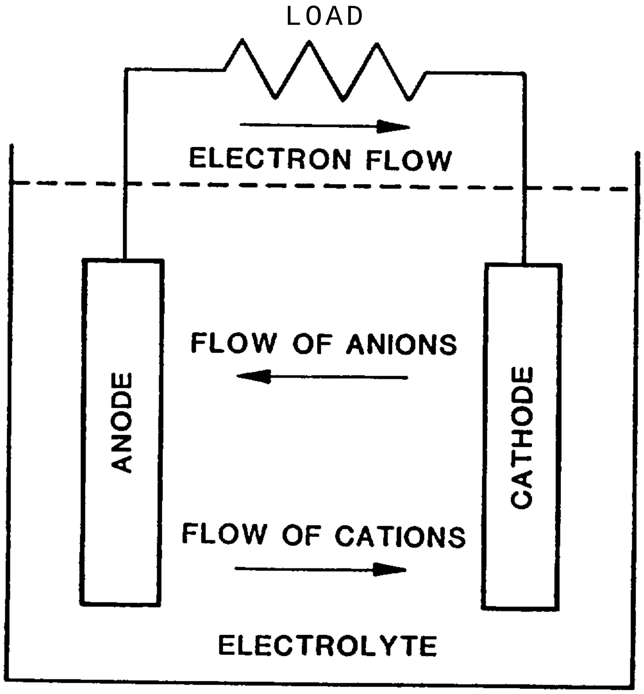


FIGURE 43. Typical battery cell.

c. Any voltage above the open-circuit voltage, when applied to a cell , causes charging current to flow through the cell. In stationary battery systems, two levels of charging voltage are used - (1) the floating charge voltage; and (2) the recharge or equalizing charge voltage. The floating charge or trickle charge is used when using batteries in a float (no load) condition. The charge level is determined by multiplying the number of cells by the voltage level recommended by the cell manufacturer. Since battery cells may be-easily damaged by excessive current, the current for a floating charge should be 40 to 100 mA. The recharge, or equalizing charge method, is used for recharging batteries which have been discharged, or are being used to supply the dc load. This charge rate is determined by multiplying the number of cells by the voltage recommended by the cell manufacturer. Chargers should be designed so that the charge will taper off to a trickle charge when the batteries have reached full charge.

5.8.2.3.1 Specific gravity. The specific gravity of a cell is the measure of sulphuric acid strength in the electrolyte. When the corrected specific gravity is 1:220, the sulphuric acid makes-up approximately 20 percent of the electrolyte. Specific gravity is measured by use of a hydrometer as depicted in figure 44.

5.8.2.3.2 Capacity. The capacity of a cell is the measure of its ability to perform work. This is expressed in ampere-hours (Ah) for a given period of time between the initial load being connected and the time final voltage is reached. One ampere for 8 hours equals 8 ampere-hours. Batteries are typically rated for comparison purposes at the 8-hour rate of discharge to a final voltage of 1.75 volts per cell. As an example, a 160-Ah battery would be capable of delivering 20 amperes for 8 hours before its voltage drops below 1.75 volts per cell. At this point the battery must be recharged.

5.8.2.3.3 Temperature. High temperatures increase chemical activity in the cell, and low temperatures decrease activity. Uniform cell temperatures are essential to maintain the activity of all cells at the same level. Sources of radiant heat such as sunshine, radiators, or steam pipes should be shielded from the batteries to prevent more than a 5 °F (3 °C) variation between the warmest and coolest cells. Normal operating temperatures are between 60 °F (17 °C) and 90 °F (32 °C). Open circuit voltage is affected by temperature. Temperatures above 77 °F lower the charge voltage by approximately 0.0040 volts for each degree over 77 °F. Temperatures below 77 °F raise the charge voltage by the same rate. On discharge, the reverse effect is obtained. High temperatures increase battery voltage and low temperatures lower it. This effect is caused by an increase in internal resistance of the cell and slower diffusion of the electrolyte at lower temperatures. Battery capacity is increased by higher-than-normal temperatures, and decreased by lower temperatures. This effect varies with the discharge rate of the cells. It is less for low discharge rates and more for high discharge rates. An approximate rate is 0.4 percent per degree Fahrenheit. Since a battery in float condition is receiving just enough charge to overcome local action losses, high temperatures require higher charge currents.

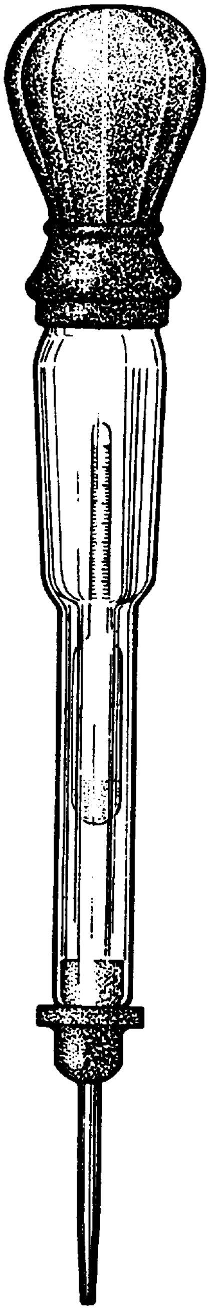


FIGURE 44. Hydrometer.

5.8.2.3.4 Calculating battery requirements. To obtain the desired operating voltage, several cells are added together to form a battery bank. To determine the required battery size, the average current drawn by the load must be determined. The average current drawn by the load occurs at the average discharge voltage, and the average discharge voltage depends on the rate of discharge. Since there is a small amount of internal resistance in the battery, as the rate of discharge increases, the initial voltage decreases, causing the average discharge voltage to be lower. Therefore, the average voltage is between the 1.75 V minimum per cell and the approximate 2 V per cell initial voltage. Typical average voltage per cell is between 1.78 and 1.93 V, depending on the discharge rate. The following formula is used to provide an approximation of the average voltage:

$$V_a \quad V_f + \frac{2}{3}(V_i - V_f)$$

where: Va = average voltage

Vi = initial voltage

Vf = final voltage

To calculate the number of cells required, the desired voltage is divided by the average discharge voltage. For a 48-Vdc battery system, the number of cells would be 48 divided by 1.87, equaling 25.6 or 26 cells. The Ah capacity of the battery cell is determined by the size and number of lead plates used. Manufacturers normally offer a number of battery types, each having its own range of capacities. To determine the size of the battery required, use the following procedure:

- Determine the estimated load by using 2 V per cell.

- Determine the reserve time desired.

- Compare the information with manufacturers specifications and characteristic curves.

- -Select the cells that meet the requirement.

5.8.2.3.5 Types of storage batteries. There are three types of wet-cell storage batteries that can be used: (1) the lead/antimony acid, (2) the lead/calcium acid, and (3) the nickel/cadmium acid. Lead/antimony acid batteries have plates that are hardened by antimony and contain sulfuric acid as the electrolyte. The plates of the lead/calcium-acid battery are hardened by calcium. Due to the superior hardness of calcium as compared to antimony, the lead/calcium-acid battery requires less maintenance and has a longer life expectancy. The lead/calcium battery also contains sulphuric acid as an electrolyte.

5.8.2.3.5.1 Nickel /cadmium batteries. Nickel /cadmium batteries are constructed by using a posltlve plate which is a nickel wire screen or perforated plate with nickel powder electrically bonded to it. This provides an active material of nickel-oxide which produces the positive charge. The negative charge is developed in the cadmium material. Both plates are porous to provide maximum surface contact with the electrolyte. The electrolyte is a solution of potassium hydroxide and distilled water. Unlike lead/antimony and lead-calcium batteries, the electrolyte of the nickel/cadmium battery does not participate in the chemical reaction, but merely provides a conductive path between the plates. Nickel/cadmium batteries have the advantage over other wet-cell batteries. Due to the lack of chemical action within the cell, plate deterioration is less, and the battery life expectancy is much greater. They may also be stored for long periods of time, whether charged or discharged, without being damaged. The cost, however, may make use of nickel cadmium batteries in large facilities unadvisable.

5.8.2.3.5.2 Maintenance-free batteries. Gelled electrolyte (Gel-cell) batteries and electrolyte-absorbing cell batteries are classed as sealed, maintenance-free batteries. The cell casings are completely sealed, making it unnecessary to add water to the cells. Each cell or battery is equipped with a vent which opens to release internal pressure when batteries are overcharged. The vent is typically open only for a fraction of a second, permitting small amounts of gas to escape. For this reason, the sealed, maintenance-free battery does not induce hazardous gases into the air as readily as wet-cell lead-acid batteries. As a result, maintenance-free batteries may be used in equipment and operations areas with little risk of contamination of air and creation of health and fire hazards. It must be realized, though, that sealed, maintenance-free batteries may explode during overcharging if the pressure relief valve fails to open. When maintenance-free batteries are used in populated areas, they should be enclosed in a metal container to increase safety. Maintenance-free batteries have been used in portable UPS units, emergency lighting, control panels, etc. Maintenance-free batteries are also available for dc station power or as the batterv for an UPS. Althouqh it has been stated that sealed maintenance-free batteries may be installed in equipment and operations areas, it is recommended that cells used for station battery or as a component of a station UPS be installed in the same type battery room as wet-cell lead-acid batteries.

5.8.3 Battery room considerations. There is a certain amount of risk involved with wet-cell battery systems. There is always the possibility of acid spills which may be hazardous to equipment and personnel. When charging, batteries create hydrogen gas, which can be a health hazard. For this reason, storage batteries should be installed in an area that is separated from the load equipment and operations area. Consult section 480-8(a) of the NEC and section 4-2.2 of NFPA 50A for additional information on battery room design.

5.8.3.1 Battery room design and construction. Design and construction of the battery room must provide for adequate installation and operation of the battery system and must provide for adequate battery and personnel safety.

5.8.3.1.1 Construction materials and methods. The external walls of the battery room should be constructed of poured, reinforced concrete. It is recommended that windows not be installed in the outer walls of the room. If windows are installed for ventilation purposes, they should be installed high enough to prevent direct sunlight from falling on the battery cells, as this can cause uneven cell temperatures and reduced cell life. The floor of the battery room should be poured concrete. The floor should have a gentle slope from the outside to the center of the battery rack area. An adequate drain should be installed at the low point to permit drainage in case of accidental acid spills. The floor surface should be treated to prevent deterioration due to acid spills. The roof should be constructed from poured, reinforced concrete. The roof may be equipped with roof vents, such as turbines or hooded fans, to remove heat and hazardous gasses from the battery room. Ventilation is discussed in 5.8.3.1.3.

5.8.3.1.2 Battery racks. Battery cells should always be installed in racks designed for the specific battery bank to be used. Racks should be built of metal angle iron or flat iron, and then should be strong enough to support the battery cells. Also, they should be designed to hold the cells securely enough to reduce the possibility of being knocked off the rack, or moved in such a way that acid spillage occurs. An example of various battery racks is shown in figure 45. Seismic racks, such as the one shown in figure 48 e and f, should be used and mounted on adequate shock mounts in areas where seismic disturbances (natural or manmade) are anticipated.

5.8.3.1.3 Ventilation. Since wet-cell batteries emit hydrogen gas during charging, and evaporation or electrolyte may cause the presence of hazardous gasses, ventilation must be provided. One of the most effective methods of ventilation is commonly referred to as dilution ventilation, or dilution of contaminated air. This is accomplished by exhausting the contaminated air from the battery room and replacing it with clean air from outside the room. Exhaust fans should be installed in the walls or ceilings of the room, and should be able to remove the air quickly. Clean air should be brought into the room through intake fans. Appropriately sized fans should be used for this operation. The size of the fan, rated in cfm, is determined by the number of cells, maximum charge rate, cubic feet of hydrogen released per hour per cell per amp during charging, and the desired hydrogen gas buildup limit. The following formula is used to determine fan size:

$$\text{Hydrogen rate (HR)} \times \frac{\text{emission rate}}{\text{time (60 min)}} \times \text{charging current per 100 Ah} \times$$

$$\text{doubling factor} \times \frac{\text{cell capacity per 8 hr}}{\begin{array}{l}\text{Increment of cell}\\ \text{capacity passing}\\ \text{charging current}\end{array}} \times \text{number of cells}$$

For example:

$$\text{Hydrogen rate (Hk)} = \frac{0.016}{60} \times 0.24 \times 2 \times \underline{1360} \times 182 = 0.317$$

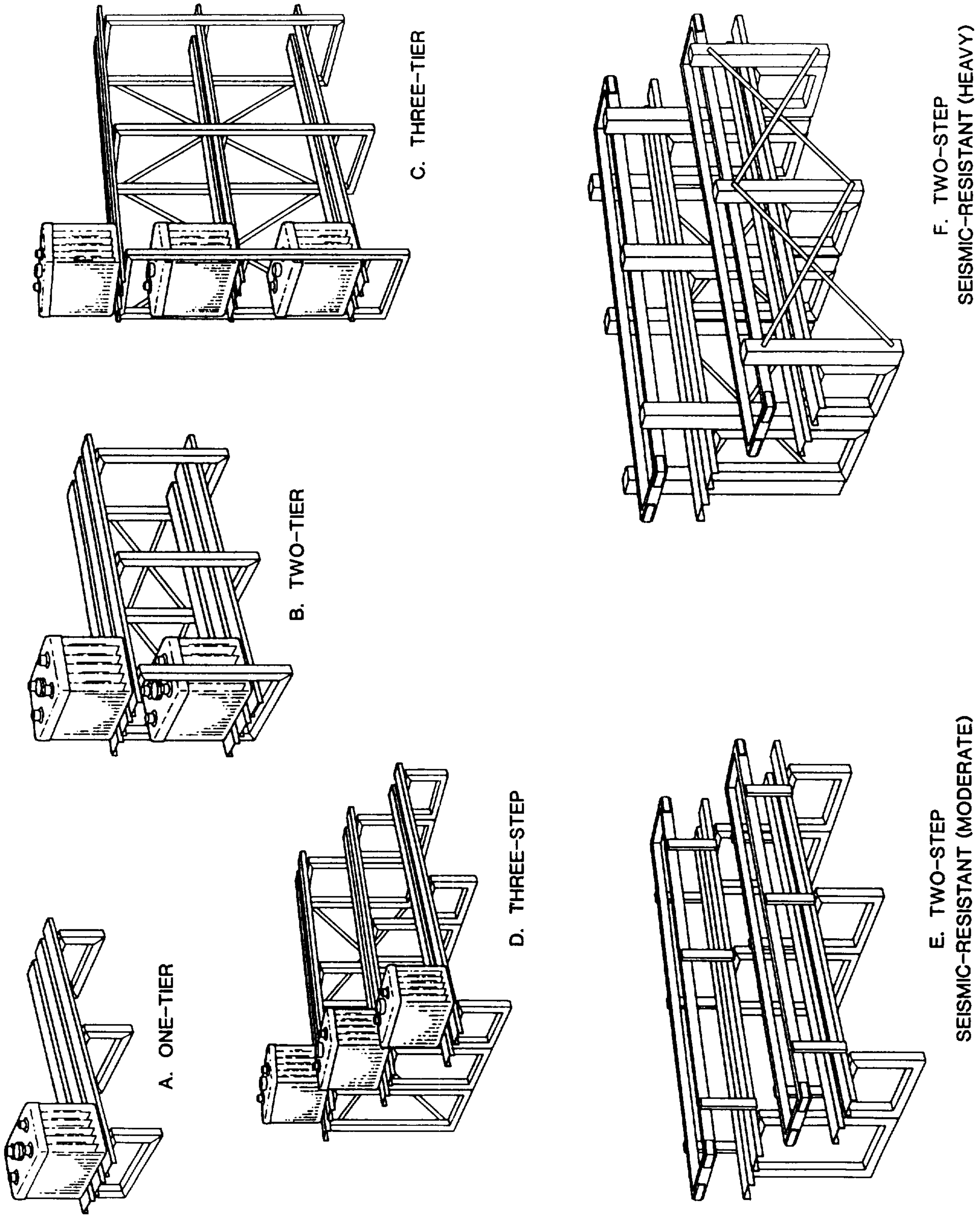


FIGURE 45. Typical battery racks.

Where:

0.016 = hydrogen emission rate per cell per ampere charge (cubic feet per hour)
60 = number of minutes per hour
0.24 = charging current per 100-Ah cell capacity at 77 “F (ampere)
2 = doubling factor for 15 “F (8 “C) rise in electrolyte temperature (above the normal 77 “F (25 ‘C))
1360 = capacity of one cell at the eight-hour rate (ampere-hour)
100 = increment of cell capacity that will pass 0.24-A current charge (ampere-hour)
182 = number of cells

Concentrations of hydrogen below 4 percent are not flammable. To meet the Occupational Safety-and-Health Act (OSHA) requirements, limit hydrogen concentration to 1 percent. The required ventilation rate is:

$$\text{Ventilation rate (VR)} = \frac{0.317}{0.01} = 31.7 \text{ cfm}$$

5.8.3.1.4 Hazardous chemical control. The electrolyte used in wet cell storage batteries is considered to be a hazardous chemical. This mandates implementing control measures to protect the facility, equipment, and personnel. Electrolyte is shipped in containers which are designed to prevent spillage or leakage. Do not store electrolyte in other containers. A special area should be designated for storage of all chemicals. This area should be isolated from all work and equipment areas to prevent accidental spillage and fire. Battery rooms must be equipped with one or more water faucets and rubber hoses, so the chemicals can be flushed from personnel, the floor or battery racks in the event of accidental spillage. When handling chemicals, personnel should always use safety equipment as indicated in 5.8.3.1.6.

5.8.3.1.5 Battery safety. Battery safety is imperative to effectively operate a battery system. This begins with proper installation of battery racks and cells. Ample space should be provided in front and behind battery racks to provide access for the performance of cell maintenance without causing undue personnel safety hazards. The area in front of the racks should provide enough space to permit installation of new or replacement cells. All electrical devices such as fans, heating and cooling units, lights, switches, and convenience outlets should be sparkproof to prevent accidental fires due to the presence of electrolyte and hydrogen gas. All battery connections must provide a good mechanical bond, not only to provide acceptable electrical continuity, but also to prevent arcing as a result of loose connections. No open flames, like those created by soldering or welding torches, should be used in battery rooms. Spare battery cells should be stored without electrolyte in designated storage areas only, and should be covered to prevent foreign matter from falling into them.

5.8.3.1.6 Personnel safety. Personnel safety in a storage battery room is also of prime Importance. Hazards such as chemical burns, respiratory difficulties, and electrical shock are present. When installing or maintaining wet-cell batteries, personnel should wear protective clothing such as rubber aprons and gloves to reduce the possibility of acid burns. Eye protection is also recommended. Respiratory masks designed to reduce gasses to a negligible level should be used. Since the possibility of accidental spills exists and may cause serious personnel injury, eye wash basins and showers should be installed in the battery room. Since the person who comes in contact with electrolyte may be unable to see and must react quickly, eyewash basins should be equipped with a large lever or foot pedal as shown in figure 49. This will permit that person to easily activate the water valve. Showers should be equipped with water valves which can be activated by stepping on the shower floor. In large battery rooms it is advisable to install more than one eyewash basin and shower. It is equally important to protect personnel from electrical shock. All energized connections should be clearly identified and, where possible, protected with insulators. Under no circumstances should exposed wiring be installed so that a safety hazard is created. The battery room should be identified inside and outside as being a hazardous chemical and electrical shock area. Warning signs should be posted at all entrances and on or near each battery rack. Personnel should be educated in proper handling of battery cells, electrolyte, and energized battery connections.

5.8.3.1.7 Fire protection. Any materials not essential to the battery system which could be a fire hazard should not be brought into the battery room. The battery area should also be designated as a nonsmoking area. The National Fire Protection Agency (NFPA) requires an automatic water sprinkling fire extinguishing system to be installed in battery rooms. Sprinklers should be installed so that when the water spray is activated it will reach all cells of the battery bank and all chemical areas. Additional information on fire protection may be found in appendix B of this handbook.

5.8.3.1.8 Heating and cooling. The need for heating and cooling in a battery room must be based on two factors: the climatic conditions of the specific geographic area and the temperature limits of the battery cells. It is possible, especially with cooling, that the operating temperature limits of the battery cells may be such that normal air flow through the vents may be enough to provide ample cooling. If heating and cooling are required, it is essential to note that the heating and cooling units should not be a physical part of the system that controls temperature for the rest of the facility. If the systems are interconnected through ductwork, hazardous chemicals may be forced into the operations area, which could be a health and safety hazard.

5.8.3.1.9 Conductor color code practices. Voltage conductor color coding is an essential element of the power distribution system. Improper color coding can cause incorrect wiring, which results in low equipment efficiency, equipment damage, and personnel safety hazards. Standard color codes should be used for all power circuits except when other color codes are required by foreign Governments. The accepted color code for single-phase ac circuits is: phase conductor, black; neutral conductor, white; and ground conductor, green. For three-phase ac circuits the color code has not been accepted by all services. The following color code is suggested; however the National Electric Code and appropriate service documents should be followed. The suggested color code is: phase A, black; phase B, blue; phase C, red; neutral, white; and ground, green. Dc voltage circuits may use a black conductor for voltage carrying conductors (positive and negative), and a white conductor for all voltage return lines. Individual service directives should be consulted for dc voltage color codes. When conductors of the same color are used, such as with three-phase power, all conductors must be color-identified by wrapping the appropriate color tape or painting a stripe around the conductor at each termination point including the facility main switch gear and each subpanel. This will ensure proper wiring and will provide easy identification.

5.9 Power conversion, conditioning, and regulation. Most DoD facilities will require some form of power conversion to attain compatibility between installed equipment and the primary power source. The most common conversion will be to change ac power to dc. This is accomplished in several ways, depending on the load. Smaller dc power supplies generally fall into the linear, ferroresonant, or switching categories. The latter category, although very flexible and efficient, requires considerable filtering and shielding to reduce EMI to a tolerable level. In fact, recent studies by an independent computer manufacturer association strongly recommends sizing the neutral conductor at 1.732 times the phase conductor to reduce the effects of harmonics generated by switching power supplies. The simplest conversion changes ac distribution voltage to the ac voltage required by the equipment. This conversion is accomplished economically and efficiently by use of a step-up or step-down transformer. Large scale dc conversions rectify ac and then use the dc to charge batteries which provide a specified amount of power carry-through during ac power fluctuations and outages. The ac-to-dc conversion to charge batteries can then be carried a step further with the addition of a rotary or static inverter to feed conditioned ac power to critical equipment. This configuration is referred to as an UPS. Ac power regulation, usually accomplished by varying supply transformer parameters, can be very important to certain types of equipment as illustrated in table XIX. Although these variable-step transformers have definite DoD applications, their response is too slow to eliminate the effects of momentary interruptions and fast-rising transients. The ultimate conditioning and regulation of ac supply voltages uses several devices to control, isolate, and protect the input to subscriber equipment as illustrated in figure 46. Power conversion for noncritical loads must be carefully weighed due to initial costs and, with converter (inverter) efficiencies ranging from 65 to 95 percent, proportionally higher utility costs.

5.9.1 Special power considerations for communications and computer-based equipment. Space allocated for computer-based equipment is unlike any other area in a facility. Due to the sensitive nature of this equipment, special electrical and mechanical systems are required. Special air distribution systems with strict humidity and air filtration control are required (see volume III of this handbook). Fire detection is extremely important for computer areas. A system called very early smoke detection apparatus (VESDA)

TABLE XIX. Generalized effects of fluctuating ac utilization voltage.

EQUIPMENT	10 PERCENT UNDERVOLTAGE	10 PERCENT OVERVOLTAGE
Resistance heating	Equivalent heating takes 25 percent longer	Heating elements experience excessive oxidation
Lighting	15 percent fluorescent and 30 percent more incandescent lamps required to obtain same illumination level	Fluorescent ballasts operate at elevated temperature and incandescent lamp life can be reduced by 70 percent
Magnetic devices	Relays operate slowly, may chatter and open contacts	Contact surfaces wear faster and insulation breakdown may occur
Motors	Starting torque reduced by 19 percent and higher operating temperature	12 percent increase in starting current and higher torque may stress shafts, gears
Electronics	Output may be decreased by 20 percent or an oscillator may drop out	Failure of ICs, capacitors, and other components greatly accelerated

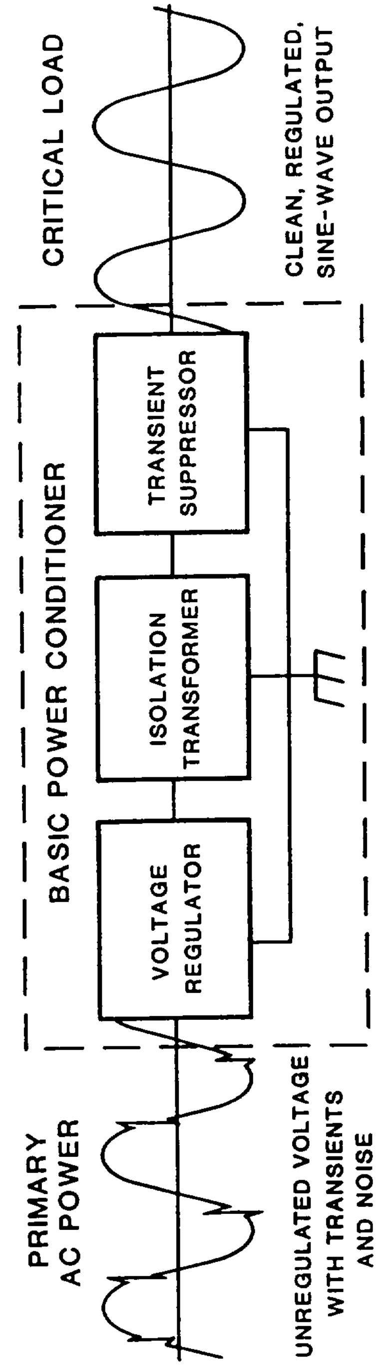


FIGURE 46. Power regulation, isolation, protection configuration.

is typical of devices used to trigger fire control systems (see appendix B of this volume). Grounding of power distribution and equipment must follow DoD and NEC criteria. Proper grounding is essential for personnel and equipment safety as well as control of static electricity. The previously mentioned full-time power monitor is a useful tool in linking unexplained computer malfunctions to power system disturbances. An UPS of some form is a must for critical DoD computers. An UPS not only provides clean power, but will continue to supply power for a specified time during primary power interruptions. The capacity of uninterruptible power that is required is a function of how important the computer is to the mission. As a minimum, an UPS battery system should provide ample reserve to permit an emergency power source to come on line. Some computer manufacturers are recommending dedicated power distribution systems. These systems only serve the computer area, and have a dedicated power distribution panel (usually fed by an UPS) and orange-colored outlets for identification. A dedicated system offers some advantage in that noise generating equipment is not on the same circuit. Federal Information Processing Standards (FIPS) Publication 94 should be reviewed when planning a computer-based electronics system.

5.9.1.1 Decentralized power distribution. In large, multifloor buildings where office equipment and small computers are in use, it is advisable to install a separately derived power source as defined in the NEC. This power source will use a dry-type transformer and, as a separately derived source, the interconnection of neutral and equipment ground (green wire) is permitted. This arrangement helps isolate the equipment being served from other equipment and reduces the effects of harmonics in the power distribution system.

5.9.1.2 Use of outlet surge protectors. The use of multiple-outlet surge protectors at the end of extension cords for small computers and business equipment is discouraged. These cords present a safety hazard both from tripping and from liquid being spilled in the outlet box. There are several wall-outlet surge protectors available that replace the standard wall outlet without changing the wall box. These outlets are produced by major manufacturers of electrical distribution equipment and meet UL and IEEE standards for surge protection. They are also available with locking-type plugs to reduce the chance of accidental power disconnection. If, for some reason, a multiple-outlet extension cord is used on a temporary basis, a unit should be selected that has been rated under UL Standard 1449 for its ability to limit transients.

5.9.2 Uninterruptible Power Systems (UPS). As implied, an UPS will provide a continuous ac output when the primary ac source is interrupted. Power for the UPS inverter is” drawn from the UPS-rectifier during nomal operation, with the batteries on float charge. When a power outage occurs, power for the inverter is automatically drawn from the batteries. This method of maintaining computer power quality has the advantage of zero switching time when the primary power is interrupted. Additionally, the battery bank is an effective absorber of power line noise and other transients. See figure 47 for basic UPS modes of operation. Mission requirements will dictate the type of UPS needed and whether single or multiple modules are required. A sample DoD power consumption data collection sheet (see appendix A of this handbook) is useful in sizing an UPS once mission requirements have been established. In filling out this form, care must be taken to ensure that computer-controlled environmental systems essential to critical load functions are included. Other than cost, the only other major caution in selecting an UPS is to make certain that the harmonic content of the reconstructed sine-wave output does not exceed 5 percent total harmonic distortion (THD) and that no single harmonic exceeds three percent. Additional information on DoD power systems is contained in DoD Construction Criteria Manual for Major Fixed Command, Control, and Communications Facilities Power Systems (DoD 4630.7M).

5.9.2.1 Rotary UPS. The rotary UPS typically uses a battery system to power a motor generator that feeds the critical load. This is a lower initial cost combination that provides very clean sine-wave power. The two factors that make a rotary UPS undesirable for most DoD facilities are the audible noise produced and the requirement to periodically replace bearings. Motor generators can also be coupled directly to the incoming ac power and use inertia to ride through momentary (less than 500 ms) power interruptions. The output from such an arrangement produces clean, isolated power, and can be configured to provide a power outage signal to the computer to go through an orderly shutdown. Another variation on the motor generator concept has an application in transient protection where a dielectric coupling between the motor and generator provides maximum isolation from the commercial power grid. In this particular motor generator application, the input power can be either ac or dc and, if required, the generator can provide 50-, 60-, or 400-Hz power to the critical load. Motor generators are also available that can meet TEMPEST isolation requirements. Sine-wave power generation by rotary machines is an economical method that results in good regulation and sinusoidal wave quality.

5.9.2.2 Solid state UPS. In addition to the rotary method, a sine wave may be generated by a linear oscillator, ferroresonant inverter, stepped square wave, switching, or digital synthesis. Early versions of sine wave generators used SCRs to switch the dc input (square wave). The SCR method was efficient, but required considerable filtering to eliminate high harmonic content from the produced sine wave. The ferroresonant inverter approach also suffers from excessive harmonic distortion unless extensive filtering is used. There are designs of the ferroresonant inverter that permit standby UPS. In this configuration, utility power normally flows through a power conditioner to the load and when a power failure occurs, a transfer controller switches the load (in less than 1 millisecond) to a battery-powered dc-to-ac inverter. As expected, the standby UPS is less expensive than a full-time one, but damage-level transients are coupled to the load until a primary power outage is detected. Power isolation coupled with a standby UPS could be a viable power system for noncritical computer-based systems. Figure 48 illustrates the standby UPS concept. Most of the full-time, solid state, UPS systems use microprocessor-controlled digital synthesis pulse-width modulation (PWM) to generate ac for a critical load. Figure 49 is a block diagram of a typical simplex, full-time UPS.

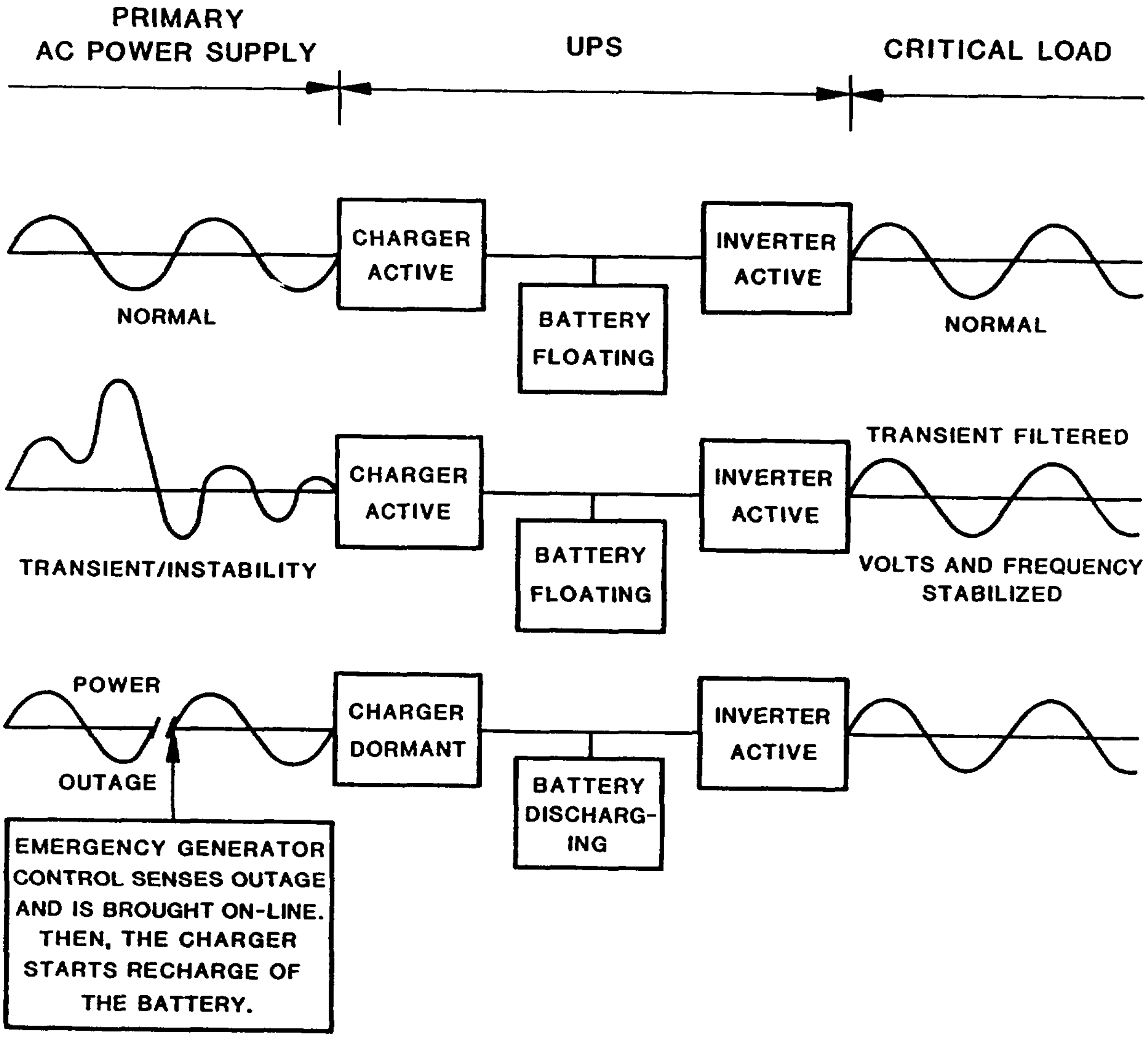


FIGURE 47. Simplex UPS modes of operation.

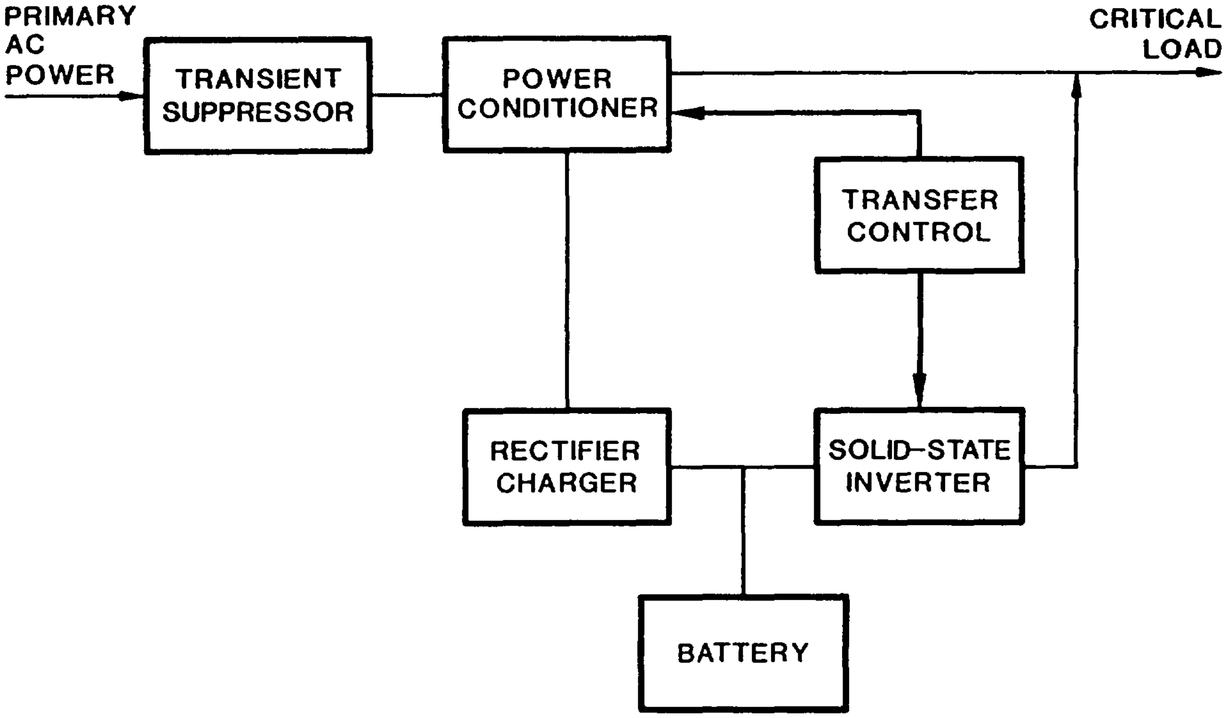


FIGURE 48. Off-line UPS.

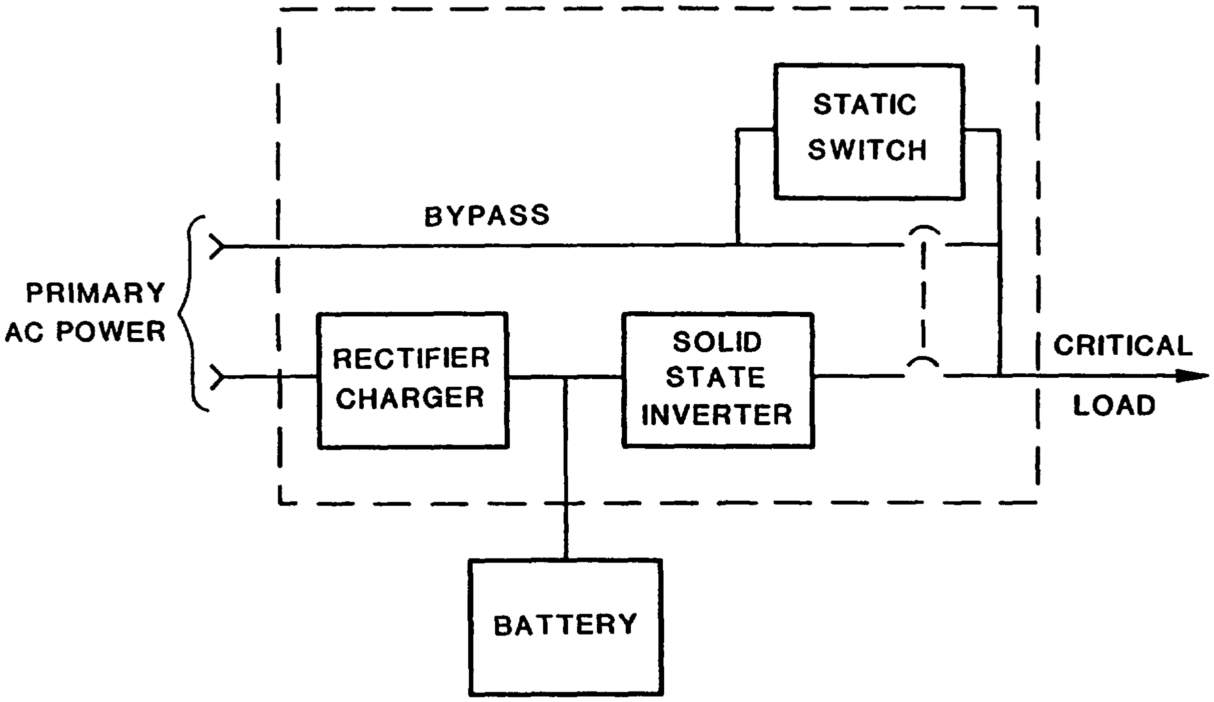


FIGURE 49. Simplex. full-time UPS configuration.

5.9.2.3 No-break generators. The term no-break generator refers to a motor-generator hat is equipped with a heavier flywheel (mechanical energy storage) to ride out momentary power interruptions. Some versions have been developed that utilize a magnetic clutch to couple an emergency generator to the critical load when an interruption of primary power is detected.

5.9.2.4 UPS bypass. Good engineering practice provides either an automatic or manual UPS bypass. This reconnection to primary ac power is necessary during a complete UPS bypass. This reconnection to primary ac power is necessary see figure 49).

5.9.3 Voltage regulation. Most manufacturers of conditioned computer power equipment refer to the voltage regulation and transient suppressor stage as the power conditioner. Automatic voltage regulators are available in several different forms. Recent designs combine solid-state sensing with buck-boost variable transformer circuitry. Ac voltage regulators are relatively inexpensive and efficiencies approach 100 percent. As previously indicated, variable transformers cannot effectively cope with fast-rising transients, but can do an excellent job of ac voltage regulation. In fact, most are capable of regulating input variations of ±15 percent to ±0.0075 percent on the load side. This means that for a 120-Vac output, a 0.0075 percent regulator, designed for the +15 percent input voltage range, will maintain an output between 119.1 and 120.9 Vac during input variations between 102 and 138 Vac. Information gathered during the site survey plays an important role in determining whether voltage regulation is required for the facility noncritical load. In locations where power brownouts are common and two independent ac power sources are available, subcycle, solid-state transfer switches in combination with voltage regulators will provide an adequate power supply to noncritical computer installation. This configuration also provides an excellent building block on which the remaining elements of UPS can be added as a critical load develops. The current, industry voltage-regulation standard for a complete UPS is that the critical-load output-voltage variation will not exceed +2 percent. This standard is independent of the primary power source quality.

5.9.4 Power isolation. There are several methods to accomplish power isolation (i.e., removal of common mode noise and low-level transients). Some previously mentioned isolation devices include battery-driven inverters and motor-generators which absorb most input power irregularities and develop a clean power output. The most common approach is to use some form of filtering that passes the 50/60 Hz with very little loss and offers significant opposition to the higher noise frequencies. In the filter approach, the high-frequency noise content is shunted to ground. The current trend is to use isolation transformers in preference to power filters at the first noise reduction point. This trend is motivated by two factors - first, it is sometimes desirable to change from a delta-connected power source to a wye connection or to change line voltage, and second, filters contain capacitors that tend to puncture when subjected to high-voltage transients. Both isolation transformers and filters are very efficient at the bandpass frequency, and compared to other isolation methods, are inexpensive.

5.9.4.1 Isolation transformers. Isolation transformers act as low pass filters which pass 50/60 Hz power frequencies efficiently and shunt higher frequencies to ground. This action is a result of special internal shielding which decreases the transformer primary-to-secondary coupling for higher frequencies and offers a high capacitance path to ground. These transformers also work in reverse if the connected equipment is a noise generator by preventing noise feedback into the power grid. Under ideal conditions, isolation transformers have the capability to reduce a 6000-volt noise spike to an insignificant 0.00015 volt. Isolation transformers are available in single- and three-phase versions and most kilovolt ratings are available from stock.

5.9.4.2 Power filters. The recent establishment of international EMI and EMC standards for computer-based electronics equipment and the availability of excellent power-conditioning equipment has changed the placement of power filters. In general, the power conditioner (see figure 50) has replaced the large power filters at or near the facility power entrance. Physically small filters are being used at the shield or chassis level. Although these filters tend to attenuate audible and rf noise in both directions, the international standards main intent is to prevent noise generated by the equipment from being superimposed on both the common and differential mode of the connected power. This change has improved overall system reliability because the transient threat to capacitive elements of filters located near the facility power entrance is severe. Filters that are located internal to the power distribution system are basically required to withstand transients that are limited to the conductor/conduit arcing voltage.

5.9.4.3 Power filter bypass. If in the interest of protection from HEMP, a facility entrance power filter is specified by the using agency, then filter leakage-current (a-function of line-to-ground capacitance) should be dynamically monitored. This can be accomplished by adapting an adjustable protective relay that will alarm when significant changes in filter element (or insulation) values occur. To prevent excessive downtime during testing or replacement, a mechanical bypass of large-facility, power-entrance filters should be included in the initial design.

5.9.5 Power distribution. The local utility usually installs the pole or pad-mounted transformer(s) to reduce transmission line voltage to the level required by the customer. High-voltage switches and breakers that the power company installs and control are located with or near this transformer. The utility traditionally installs overhead and underground service to the building and connects to customer-provided switchgear. This portion of facility power distribution installed by the utility is called the service entrance. Most small-to-medium size facilities in the United States will be furnished a wye-connected, three-phase, 277/480 Vac system as illustrated in figure 50. This combination permits the use of smaller wire for a given demand. A neutral is provided to handle phase-current imbalances. Recent studies of wye-connected systems have revealed significant odd-harmonic power content on the neutral conductor. As a result of these findings, it is now recommended that the neutral conductor be sized to carry at least 1.732 times

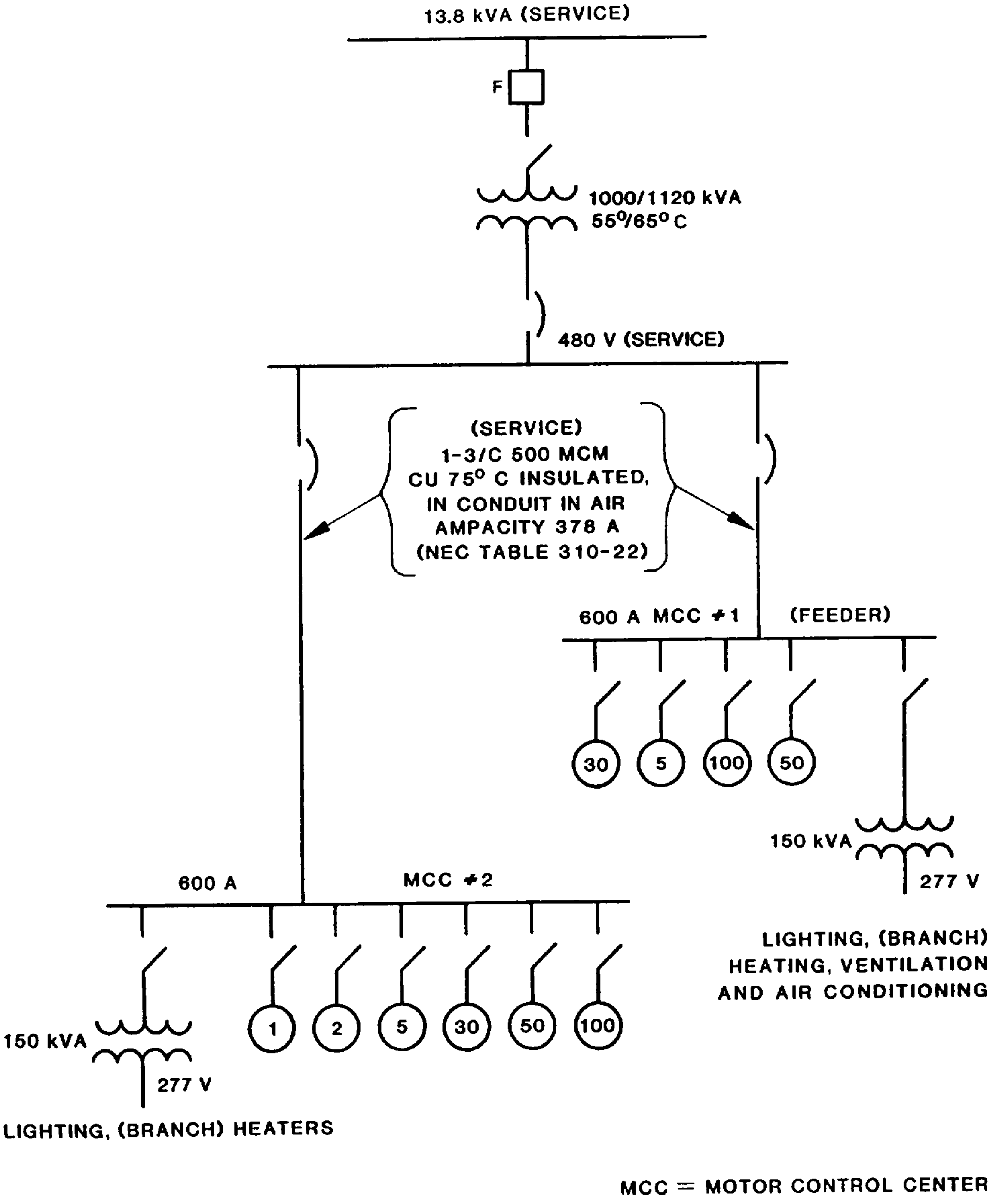


FIGURE 50. Representative ac power distribution diagram.

the phase current. From the customer-provided switchgear, distribution to other power centers is by feeders. In the case where 120 Vac single-phase is required for branch circuits, dry-type transformers are used to reduce the voltage. The single line power diagram is the first step in determining location of power distribution centers, transformers, breakers, and other protective devices. Dc power distribution also requires careful planning and engineering. In dc systems, inadequately sized conductors and improper connections can result in unacceptable voltage drop or poor power supply regulation. Ac and dc power distribution schemes, such as simple radial, mixed radial, and parallel, primary selective, primary loop are covered in 5.7 of this volume.

5.9.5.1 Circuit breakers and distribution panels. The common designations for ac distribution equipment are listed in table XX. The location of medium-to-large motor control centers (MCCs) and other switchgear must be carefully planned so that the equipment stays dry and has adequate ventilation. The current version of the NEC should be consulted for information on breaker and wire sizes, as well as location of distribution panels.

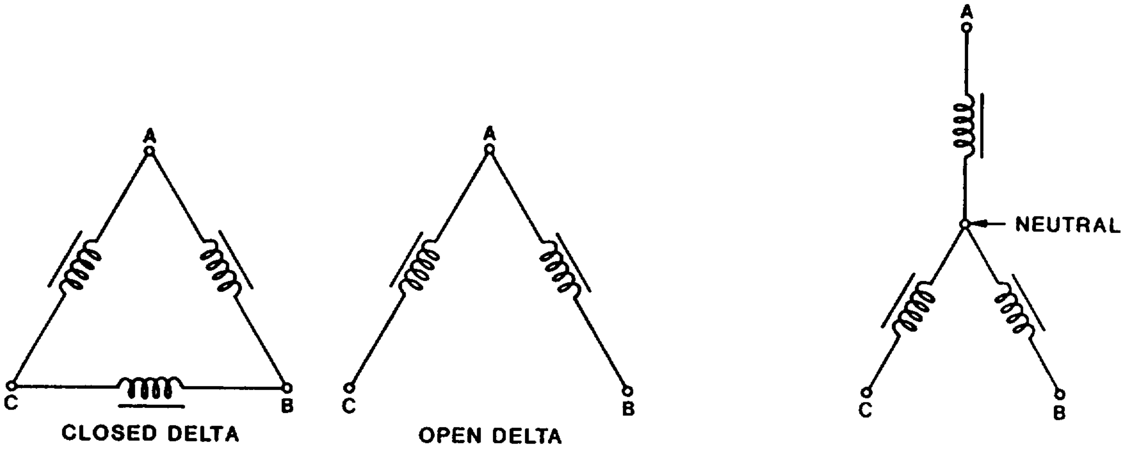
5.9.5.2 Special applications for fuses. In a facility that must be capable of returning quickly to operation following a major equipment fault (short circuit), fuses should be considered in combination with breakers as insurance against breaker failure. Fuses are readily available for almost any application; therefore, custom-designed fuses should be avoided since spare supply may be limited to a single manufacturer. The basic types of fuses, characterized by reaction time, interruption rating, and current-limiting property are designed as standard, time delay, current limiting, and dual element. The Underwriters Laboratories (UL) has developed basic performance and physical specifications for fuses. The most used of the UL standard classes (under 600 V) are RK 1, RK 5, G, L, T, J, H, and CC.

5.9.5.3 Ground-fault circuit interrupters (GFCI). The personnel safety aspects of GFCI protection are vitally important to DoD facility design. GFCI devices installed on 120 Vac circuits continuously compare the current in the ungrounded phase conductor with neutral current. On a 240 Vac circuit, the same principle is used except the comparison is made between two phase conductors or the phase conductors and neutral. On 120 Vac circuits, if the current is less than in the phase conductor, a ground fault exists since a portion of the supply current is returning by a path other than the neutral . On distribution level ac voltage, a ground fault exists when the sum of the currents in all three conductors does not equal zero. A current imbalance as low as 5 milliamperes on UL Class “A” GFCIs will interrupt the circuit. (The problem discussed in section 5.9.5 on odd-harmonic current content on the neutral also impacts on selection and use of GFCIs.) Ground-fault breakers are also available for panelboard installation as the main or branch circuit breaker (75- to 3000-amp continuous rating). Panelboard ground-fault breakers are usually adjustable for trip current and interruption time. This type breaker should be considered for use in repair shop and similar activities where personnel safety is paramount.

TABLE XX. Commonly specified power distribution centers.

Equipment designation	Functional description
Switchgear - breakers	Utility-provided high-voltage distribution and overcurrent protection (vacuum or oil breakers)
Unit substation	Utility-provided high-voltage disconnect switch and voltage-reduction transformer with low-voltage magnetic breakers
Motor control center	Customer-provided large cabinet houses motor starters, molded-case circuit breakers, etc.
Switchboard	Customer-provided free-standing cabinet houses overcurrent protectors to motor controllers and miscellaneous power circuits in building
Panelboard	Customer-provided wall cabinet for low-voltage distribution to lighting and receptacles also provides overcurrent protection with molded-type circuit breaker

5.9.5.4 Distribution transformers. The use of an open-delta connected transformer (see figure 51) in secondary power distribution must be avoided. The only advantage an open-delta configuration offers is lower cost (i.e., only two transformers are required for three-phase power). A closed-delta secondary is also a poor choice compared to a wye connection. The reasons for avoiding a delta-connection are” based on personnel safety (higher voltages to ground), poorer voltage regulation, and poor transient suppression. Delta-connected secondaries do offer slightly higher electrical efficiency and better reduction of some utility-generated harmonics. In transformer selection, the method of cooling and type of winding insulation used are major factors. Cooling methods fall into three classifications: either liquid, ventilated, or sealed. Since dry-type transformers are air cooled, nonexplosive, and nonflammable, they are ideal for indoor use. The limitation of dry-type transformer reliability is their basic insulation level (BIL). However, winding insulations have been considerably improved in



A. 3-PHASE DELTA DISTRIBUTION TRANSFORMERS.

B. 3-PHASE WYE DISTRIBUTION TRANSFORMER.

FIGURE 51. Distribution transformer connections.

the past few years, and with the addition of transient arrestors, overall reliability is improved. Where the facility is required to survive the effects of EMP, the highest available BIL rating should be considered. The planner should ensure that transformers selected have a sufficient reserve to allow normal facility expansion.

5.10 Electric motor selection and control. The description of electric motors as standard or high-efficiency is not strictly defined; these are terms used by manufacturers to designate motors that have a significantly improved efficiency over standard product lines. NEMA MG 1 and MG 10 are the guidelines used to compare high-efficiency motors and individual service publications such as TM 5-811-13, Standard and High-efficiency Motors and Controllers, should be consulted for application. Section 430-24 of the NEC provides information on conductor sizing for motor loads.

5.10.1 Electric motor control and protection. A motor controller is any device used specifically to start and stop a motor. It could be a switch, circuit breaker, or other means. It does not have to open all conductors to a motor unless it also accomplishes the disconnect function. If a controller is configured to open a grounded conductor, then it must simultaneously open all other conductors. Motors are not considered part of the power distribution system, but frequently comprise a large portion of the facility electrical load. The general layout of a motor circuit is shown in figure 52. In most applications, a motor is not directly connected to the main power supply, but is fed through power conversion equipment such as frequency chargers for ac motors or switched rectifiers for dc motors. Electric motors typically have starting inrush currents considerably higher than currents when running. In a marginal ac distribution system, motors starting cause transients harmful to sensitive electronic equipment. For this reason, motor loads are usually fed on a separate bus or have “soft-start” controllers. At some facilities, cabinets designated as motor control centers house all the equipment necessary to control and protect all large motors.

> WARNING: Failure to follow NEC, OSHA, and individual service safety instructions for electric motor installation and protection may cause serious or fatal injury.

Some of the safety items to be considered include: the motor housing or frame must be grounded to a continuous earth ground, manual-motor resets should be used in an area where unexpected automatic restarting presents a hazard to personnel, operators must manually turn-off electrical supply to motors when power sags or outages occur or protectors must be provided to sense these conditions and automatically disconnect the supply. Automatically started motors that are out of sight of the operator are required to have protection against overloads or failure to start. In applications where overloads are not expected, locked-rotor protection is the only protection required. Fractional-horsepower motors traditionally use internal thermal protectors to detect “locked-rotor” conditions (see appendix

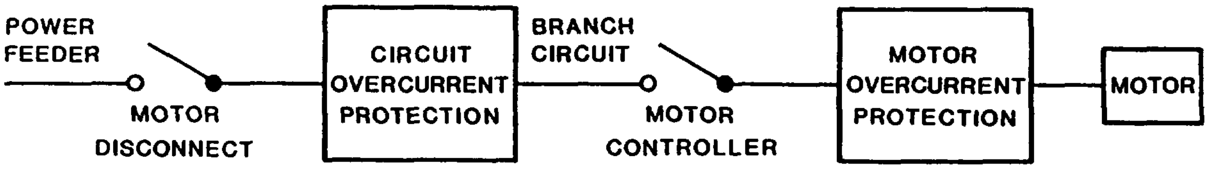


FIGURE 52. Electric motor circuit.

A of this handbook for typical locked-rotor currents). Any three-phase motor should have some form of phase monitoring protection. Typically, when the phase sequence is correct and full line voltage is present, a relay locks up and permits the motor to run. When line voltages fall below a trip point, or a phase is out of sequence or drops out, the relay disconnects the motor before burnout occurs.

5.11 Antenna rotators and satellite antennas. Antenna rotators and their remote controls are relatively vulnerable to the effects of transients and must be protected if survivability is expected. Satellite antennas (dishes) are relatively invulnerable to transients, but the associated electronics package is vulnerable to transients generated by EMP and lightning. For antenna rotators, the servo system and the motor that turns the antenna must be protected with MOVs or gas gaps as described in this handbook. If circuit boards are involved in positioning, or indicating position of, the antenna, a hybrid protector consisting of gas gaps, series inductance, and zeners will be required. For satellite antenna protection and grounding techniques, individual service manuals such as Army FM 11-487-4/Air Force TO-31-1-24 should be consulted.

5.12 Low-cost EMP/Transient protection methods. The Federal Emergency Management Agency (FEMA) has developed several low-cost approaches to transient protection for state and local Government communications facilities. The main building block of this approach consists of an rf-tight equipment cabinet with protected single-entry points for power and control of communications equipment, as illustrated in figure 53. Admittedly, this is a compromise between expensive shielded rooms (see section 5.5.6.7.6 of this volume) and no enclosure at all, but should be considered as a minimum requirement for small DoD facilities. Additional information on this approach to transient protection is contained in FEMA publication CPG 2-17.

5.13 Minimizing electrical and electronic disturbances. Electrical and electronic disturbances can be minimized by proper shielding and grounding techniques. In addition to this handbook, these techniques are covered extensively in MIL-HDBK-419 and MIL-HDBK-1195. For computer-based electronics equipment, FIPS PUB 94 should be reviewed for information on power, grounding, and life safety considerations. Electromagnetic interference (EMI) and electromagnetic compatibility (EMC) are major considerations in all DoD electronics installations. They become even more critical in overseas installations.

5.13.1 Electromagnetic interference (EMI) standards. There are currently three major world standards for technical limits on potential EMI. These cover both conducted and radiated electromagnetic emissions from data processing and electronic office equipment. In the United States, FCC rules (Part 15, subpart J) apply; in Germany, Verband Deutscher Elektrotechniker (VDE) standards 0871 and 0875 are in general use. In Japan, the Voluntary Control Council for interference by Data Processing Equipment and Electronic Office Machines (VCCI) are the voluntary standards. The equipment manufacturer must certify through testing that their equipment meets the

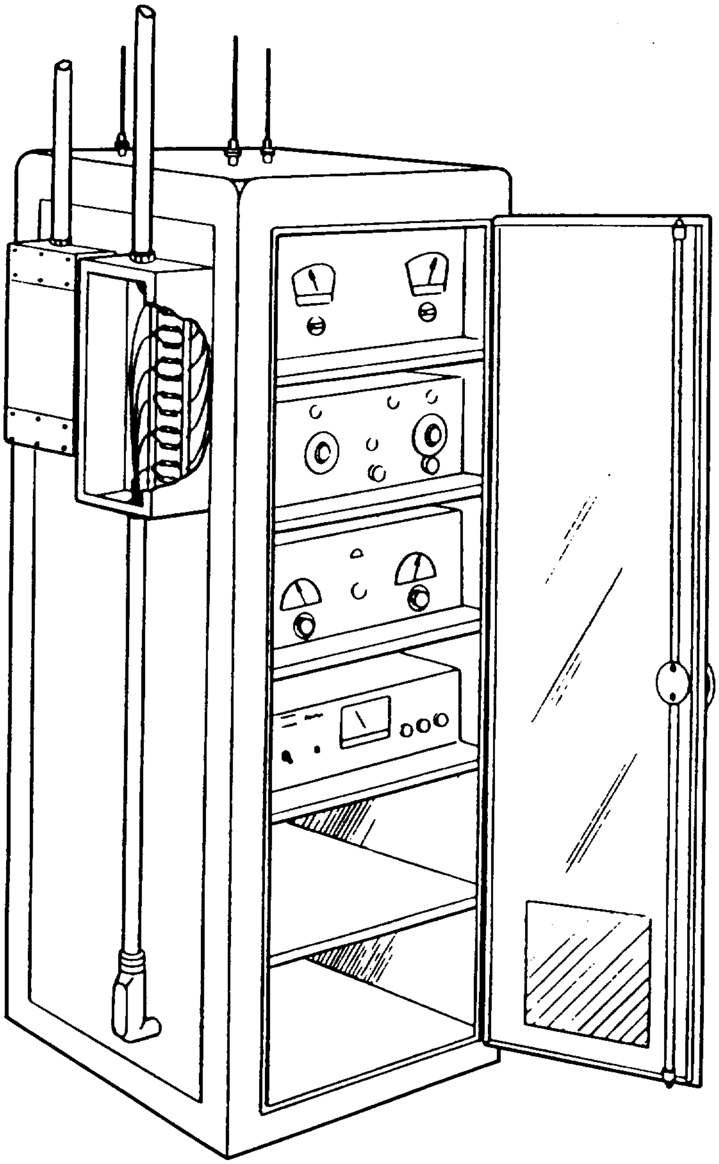


FIGURE 53. Low-cost EMP/transient protection.

standards of the country where used. It is generally agreed by manufacturers that an electronic product cannot be tested once to meet all three major EMI standards. However, it is possible that one test could satisfy all three major standards for conducted emissions, but the variations between VDE, FCC, and VCCI for radiated emissions testing appear to be too great for one test to suffice. Publication 22 of the International Special Committee on Radio Interference (CISPR), establishes EMI limits on information technology equipment that are similar to the ones established by the individual countries mentioned.

5.13.2 Electromagnetic Compatibility (EMC) solutions. The DoD Electromagnetic Compatibility Analysis Center supports the military services in the analysis and solution of EMC problems. The ECAC computer-based Technology Transfer program (TTP), provides DoD agencies the rapid data-base access required to effectively manage limited frequency resources. The ECAC service includes system reliability predictions, propagation predictions and frequency assignment information from HF through the SHF bands. The TTP programs can be used at the operational level on readily available mini- and microcomputers. The ECAC also operates a user-assistance center to assist personnel in the field in application of the analysis program. The ECAC assistance center is staffed with experts during normal working hours and can be contacted using standard DoD communications systems. Additional information on the TTP is available to DoD agencies by contacting the Electromagnetic Compatibility Analysis Center, Attn: XMTP/TTP, North Severn, Annapolis, MD 21402-1187

6. NOTES

6.1 Intended use. The purpose of this handbook is to provide basic guidance to managers and engineers of the military departments and agencies in the design and installation of power systems at DoD fixed communications and related automatic data processing facilities.

6.2 Subject term (key word) listing.

ac systems
attenuation
auxiliary power
busways
capacitance
current transformers
circuit breakers
cogeneration
computing power load
dc systems
electrical impedance
electrical resistance
electric power distribution
electric power generation
emergency power
flux density
fuses
inductance
power cables
power conditioning
power distribution
power factor
power isolation
power lines
power load
power loss
power quality
power switching
power systems monitoring and control
power substations
power measurement
power meters
power transformers
protective relays
public utilities
reactance
resistance
transformers
transient protection
transient voltage protection
transmission lines
uninterruptible power systems (UPS)
watt-hour meters
wattmeters

6.3 Changes from previous issue. This revision correlates to the previous issue in concept only. The content has been subjected to extensive change and reorganization to reflect emerging technology. Asterisks or vertical lines are not used in this revision to identify changes with respect to the previous issue due to the extensiveness of the changes.

Custodians	Preparing activity
Army - SC	Army - SC
Navy - EC	
Air Force - 90	(Project SLHC-4112)

Review activities
Army - CR,CE
Navy - YD,MC
Air Force - 50
DoD - DC,MP

ALTERNATING CURRENT (ac) THEORY, POWER USAGE DATA COLLECTION, AND USEFUL CONVERSIONS

10. Scope. This appendix provides a brief review of alternating current (ac) theory as well as a method to manually estimate ac power consumption and useful electrical /electronic/metric conversion tables. This appendix is to be used as a refresher only. For exact applications, a comprehensive text or individual military department technical publications should be consulted.

20. Applicable documents. This section is not applicable to this appendix.

30. Definitions. See paragraph 3.1 of this handbook.

40. Review of alternating current (ac) theory.

40.1 Elements. The ultimate particles of an element are called atoms. An atom consists of a small, relatively heavy nucleus with a number of lighter electrons circling it. The nucleus in turn is composed of protons and neutrons which, like electrons, are elementary particles that cannot be subdivided further.

40.2 Electric charge. Electric charge is a basic property of protons (positive) and electrons (negative). Charges of the same sign repel each other; charges of opposite sign attract each other. The number of protons in the nucleus of an atom normally equals the number of electrons around it; therefore, the atom as a whole is electrically neutral.

40.3 Electric current. The unit of electric charge is the coulomb (C). The charge on the proton is ^{+}e, and that on the electron is -e. A flow of charge from one location to another constitutes an electric current. A conductor is a substance through which charge can flow easily, and an insulator is one through which charge can flow only with great difficulty. Metals, many liquids, and gases whose molecules are electrically neutral are insulators. A number of substances, called semiconductors, are intermediate in their ability to conduct charge. Electric currents in metals consist of electron flow; such currents are assumed to occur in the direction opposite to that of electron movement. Since a positive charge moving in one direction is essentially equivalent to a negative charge moving in the opposite direction, this assumption makes little practical difference. Both positive and negative charges move when a current is present in a liquid or gaseous conductor. When an amount of charge (Q) passes a given point in a conductor in the time interval (t), the current (I) in the conductor is:

$$I = \frac{Q}{t}$$

$$\text{or current} = \frac{\text{charge}}{\text{time interval}}$$

The unit of electric current is the ampere (A), where:

$$1 \text{ ampere} = \frac{1 \text{ Coulomb}}{\text{second}}$$

Essentially, circuit analysis is performed in much the same manner as dc circuit analysis. The notation to describe dc current and voltage, network theorems, and Kirchhoff's laws still apply. However, where simple algebra provides most solutions for dc circuits, higher levels of mathematics are required to find exact solutions to ac circuitry. The most sophisticated mathematics is required for ac study because ac currents and voltages vary with time, and this means additional circuit parameters besides resistance must be considered. When the driving voltage or current sources are fixed in magnitude and polarity, as in dc circuits, the only opposition offered to the flow of current is due to the circuit resistance (R).

40.4 Ac circuit characteristics. When the voltage source and/or current vary with time, even a short section of wire reacts in some degree to the following:

a. An oppositicm to the flow of current (resistance, R)

b. An opposition to the change in current (inductance, L)

c. An opposition to the change in voltage (capacitance, C)

40.5 Development of waveforms. A voltage or current plotted versus time is called a waveform. figure A-1a, for example, is a plot of a constant dc voltage (e) versus time (t). If the dc polarity is reversed, we have the result shown in A-lb.

a. If a waveform reverses polarity periodically, it is referred to as an alternating current or voltage. If the switch in figure A-2a is moved periodically between positions A and B, the waveform in figure A-2b would result. Several of the commonly generated waveforms are illustrated in figure A-3. Parameters that are of particular interest when studying periodic waveforms are:

(1) positive peak amplitude

(2) Negative peak amplitude

(J) peak-to-peak amplitude

(4) Period

(S) Frequency

(6) Average value (dc component)

(7) Root-mean-square (rms) value

b. To understand the significance of these parameters, consider the example shown in figure A-4. In this illustration, +100 volts is the positive peak amplitude. It is important to realize that the peak positive amplitude of a waveform could be assigned a negative value if the entire waveform is below the zero axis.

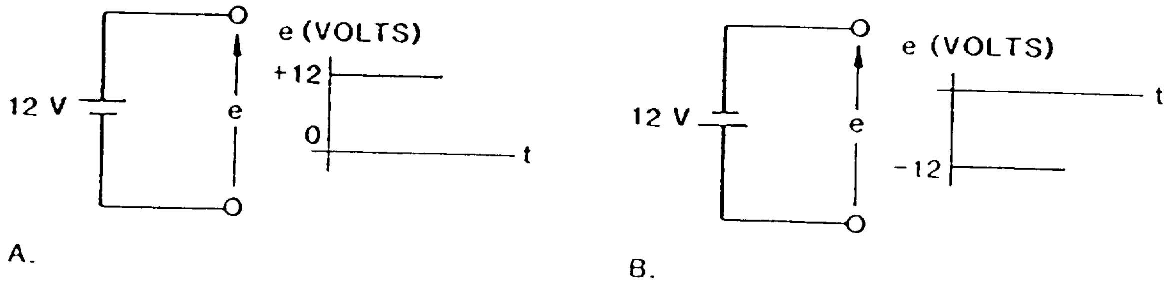
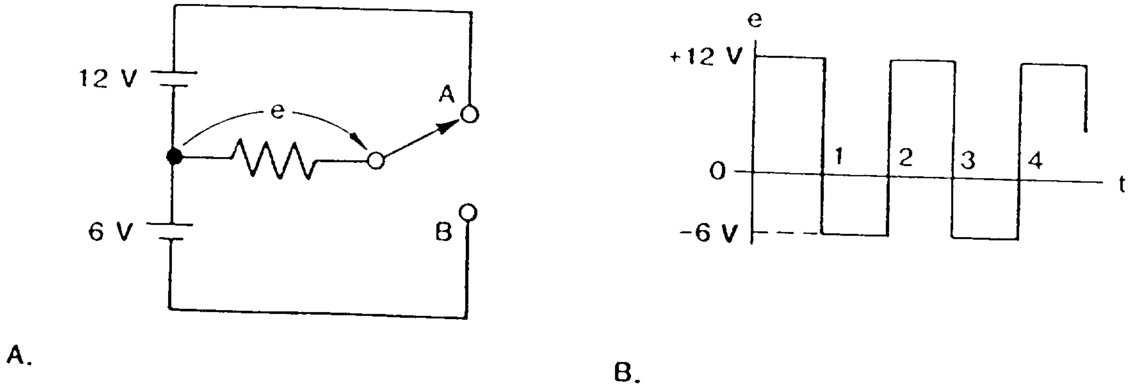


FIGURE A-1. Voltage plotted against time.



FIGUREA-2. Results of switched dc .

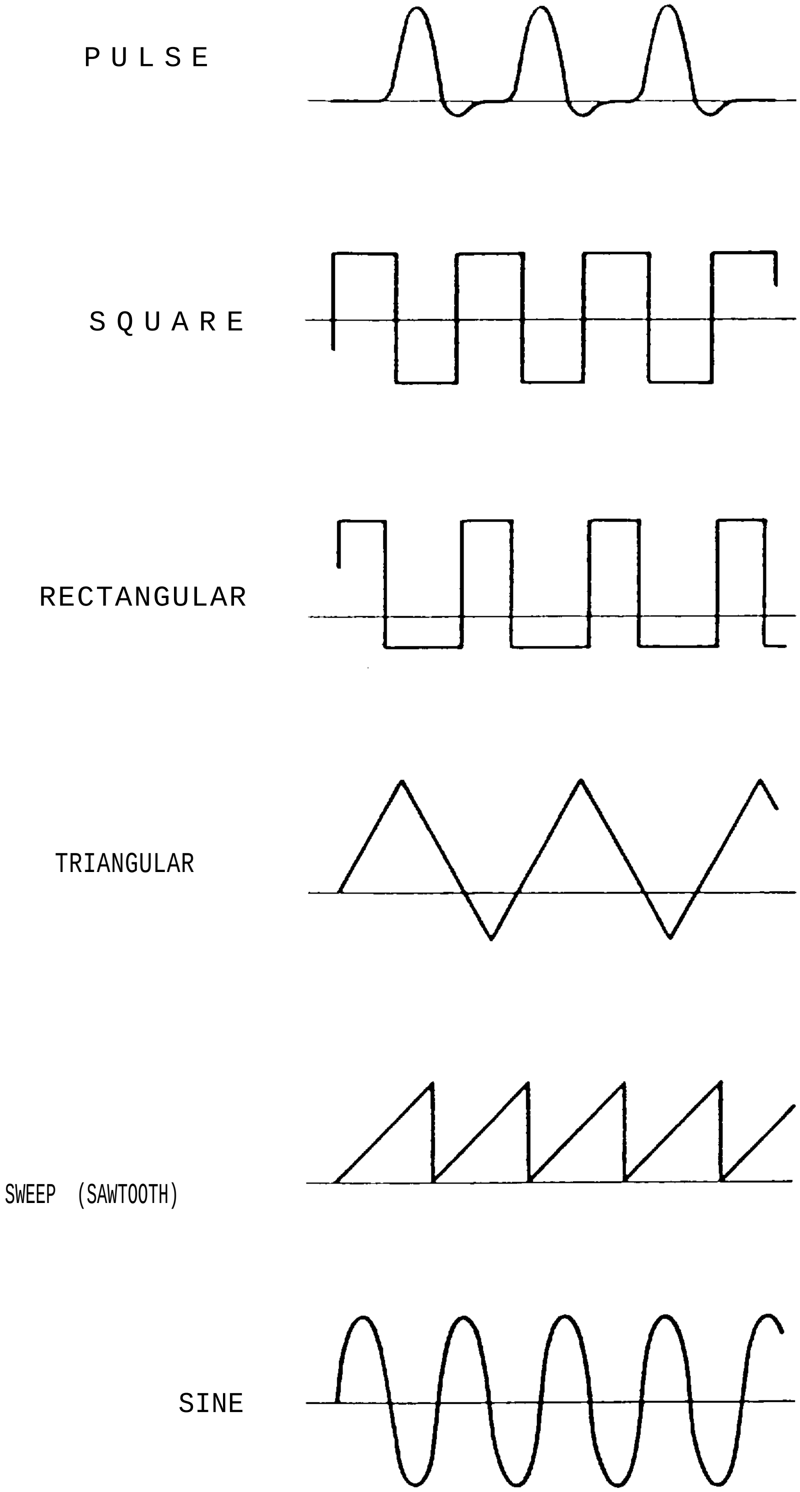


FIGURE A-3. Commonly generated waveforms.

c. The negative peak amplitude in figure A-4 is -120 volts. If all of a wave form lies above the zero axis the peak negative value will be assigned a positive number.

d. The peak-to-peak amplitude is the absolute value of the amplitude between the positive and negative peak amplitudes. Thus for figure A-4, the peak-to-peak (abbreviated p-p or pk-pk) amplitude is 220 volts.

e. The period (T) of a waveform is the length of time it takes to repeat itself. Thus in figure A-4 the period is T = 10 sec.

f. The frequency (f) represents the number of times the waveform repeats itself in a given time interval. If the time interval is equal to the period, the waveform has completed one cycle. Frequency and period are reciprocal quantities expressed by:

$$f = \frac{1}{T}$$

$$\text{and, } T = \frac{1}{f}$$

The hertz (Hz) is the international unit used to express cycles per second therefore:

$$1 \text{ Hz} = \frac{1 \text{ cycle}}{\text{sec}}$$

With the adoption of Hz as the international unit, the expressions 10,000 cycles/see or 10 kilocycles/see (10 kc/s), become 10,000 Hertz or 10 kilohertz (10 kHz).

g. The average value of some periodic waveform is its average value as determined over a time interval equal to the period T. The average value is the dc component of a waveform, and it represents what a dc voltmeter would read if it were driven by a voltage waveform. To find the average value of any function, say $y = f(x)$, over some interval , as shown in figure A-5, it is necessary first to determine the area bounded by the curve (shaded area) during this interval and then to divide this area by the length of the interval. This yields the average value. In figure A-5, some of the area is positive and some is negative. To obtain the net area, subtract the negative area from the positive. If the negative area exceeds the positive area, a negative average value will result. Mathematically, the average value of a waveform is expressed as an integral:

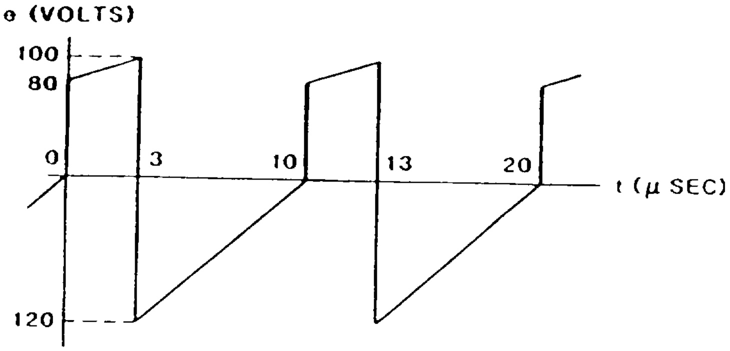


FIGURE A-4. Peak voltage generation.

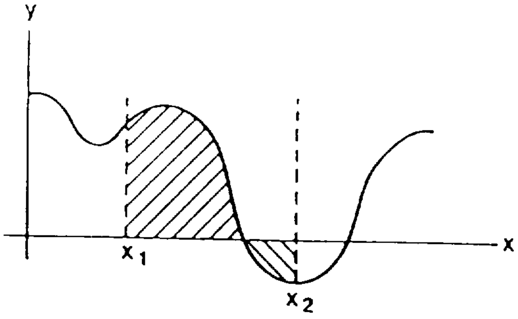


FIGURE A-5. Average waveform value.

$$\text{Average value} = \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} f(t)dt$$

where $t_2 - t_1$ is the time interval over which we seek the average value, usually equal to the period, and

$$f(t)dt$$

is a mathematical symbol used to designate the area under a curve (in this case a plot of some f(t), meaning function of time) over an interval $t_2 - t_1$. A simple interpretation of the integral is:

$$\text{Average value} = \frac{\text{the net area between the waveform and the time (t) axis during a given time interval}}{\text{the given time interval}}$$

h. The root-mean-square or effective value of a waveform represents developed power. For example, if some periodic voltage waveform is impressed on a resistor, the resistor will dissipate heat. This heat dissipation will occur even if the average value of voltage (or current) is zero. In this case, the direction of current flow does not matter - current flow through the resistor causes energy loss. By definition, the effective or rms value of a voltage (or current) waveform is that value which develops as much average power in the resistor and an equivalent dc voltage. To determine the rms voltage value of a waveform, the instantaneous power at any moment in time is given by:

$$p = \frac{e^2}{R},$$

where e is the instantaneous voltage across the resistor R.

There are two kinds of power we are usually interested in - instantaneous power (p) and average power (P). The instantaneous power for any waveform of voltage or corresponding waveform of current is given by:

$P = ei$

P = instantaneous power
e = instantaneous voltage
i = instantaneous current

The current and voltage waveforms need not be the same. In fact, most ac circuits display ledding or lagging currents and voltages. To determine average power in any device, and with e and i waveforms, generate the p curve by the P = ei equation, and then determine the average value of the p curve in a manner similar to the average voltage or current method discussed above. For a waveform of period T,

$$P = \frac{\text{area under the p curve during the interval T}}{T}$$

The average and rms values of a waveform will not be the same, therefore, rms rather than average voltage or current values is used when computing power.

40.6 Power generation. The most common form of electric power is produced by generators which convert mechanical energy to electrical energy. Most of these generators develop an alternating voltage (and current) with a waveform that closely resembles figure A-6. Because this type of waveform is based on a trigonometric function called the sine, it is referred to as a sine wave or a sinusoid.

40.7 Voltage. In order to make current flow through a conductor, an electrical pressure is required to separate the electrons and protons. This electrical pressure (also called the electromotive force or the potential difference) is known as voltage, and the basic unit of measure is the volt.

40.8 Constant potential systems. The most common type of system for electrical distribution is the constant potential type where the voltage is kept as constant as possible and the current varies with variations in the load. This system is further subdivided into alternating and direct current.

40.9 Alternating current (ac) systems. Current in alternating current systems first flows in one direction around a loop of conductive material, then reverses and flows in the other direction at-regular recurring intervals. Most power systems are of the alternating current type. To understand how this type of current is produced, a simple two-pole generator is described. Basically, this generator consists of a north and south magnetic pole and a loop of wire fixed so it can rotate between the poles as shown in figure A-7. As the loop rotates between the poles, a current is induced which flows in one direction through the first 180 degrees. The induction of current occurs when the loop cuts the magnetic lines of force flowing from the north to the south pole. When the loop reaches the 90 degree point, the maximum number of lines are being cut and the induced current is at a maximum. When the loop reaches the 180 degree point, it is no longer cutting any lines of force and the current is zero. One complete revolution of the loop constitutes one cycle because the current has gone from zero to maximum value twice as shown in figure A-7.

40.10 Single-phase power. The current produced by this generator is single-phase because only one source of induced current (one loop or coil) is used between the poles. An electrical system can be identified by the number of wires and the voltage between the wires. For example, figure A-8 shows a single-phase, two-wire, 120-volt syste m . The notation for this system is 1O-2W-12OV. A single phase, three-wire, 120- /240-volt system would be shown as 1O-34-120/240V.

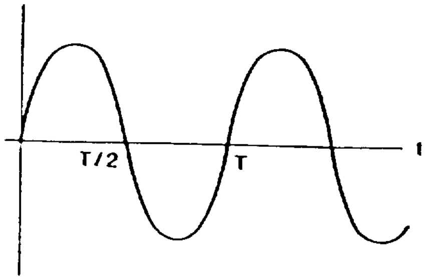


FIGURE A-6. Sine wave generation.

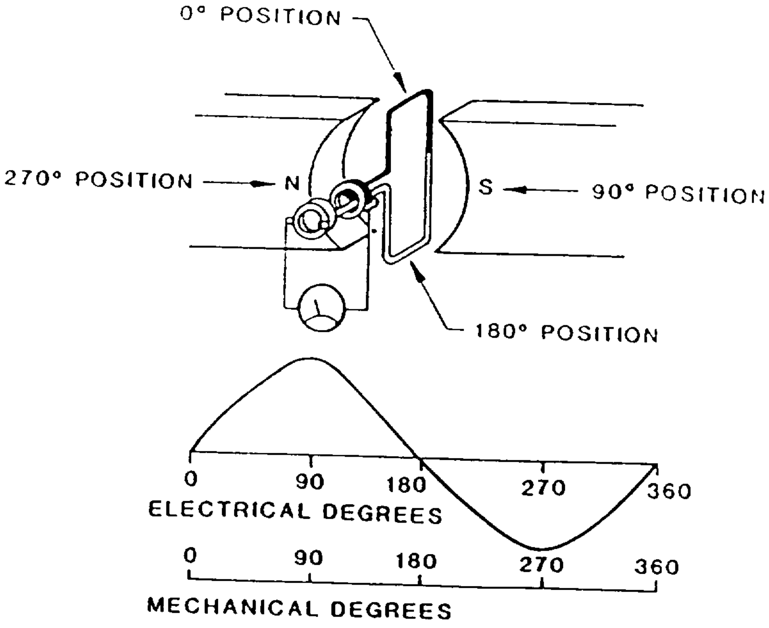


FIGURE A-7. Generator construction .

40.11 Two-wire systems (10-2W). In the single-phase, two-wire system (figure A-8), one of the two wires from tne generator is connected to ground and is called the grounded conductor or neutral. The other wire is called the phase conductor. Normally, the voltage difference between these conductors is 120 volts. In this system the current in one conductor equals the current in the other. Facilities that use single-phase current usually have very light electronic and lighting loads.

40.12 Three-wire systems (10-3W). In this system, there are two voltages available which provide the advantage of simultaneously obtaining a high voltage for heavy loads and a lower voltage for lighter loads. Figure A-9 illustrates the three-wire, single-phase system. In this particular wiring arrangement (called a wye), the voltage between the phase conductors is approximately twice the voltage between the neutral and either phase conductor. The current in the neutral (grounded) conductor is equal to the difference between the currents in the phase conductors. When the connected load between the neutral and one phase equals the connected load between the neutral and the other phase, the loads are balanced. Under this condition, the currents in the phase conductors are equal and neutral current flow is zero.

40.13 Three-phase power generation. If three coils (or loops) separated by 120 degrees are used, the current is induced in each one by the poles at a different time with the result shown in figure A-10. Note that the illustration shows a much smoother sequence of impulses than the earlier single-phase illustrations. Single-phase power has not become obsolete by the increased use of the three-phase concept as each type has its own specific application based on the type of load to be served.

a. As stated before, three-phase power is, in effect, generated by three precisely spaced single-phase coils. This system usually consists of four conductors, although three conductors are sometimes used. Each conductor represents one phase. As the three-phase power is produced in the generator, one of two methods is used to connect the coils for distribution to the load:

The Y (wye) or star connection
The A or delta connection

Normally the delta generator connection employs three wires and the wye employs four wires.

b. Three-wire systems (30-3W). Figure A-n shows a three-phase, three-wire system using a delta connection. All three wires are considered phase conductors. Any 1O-2W, 240-volt load may be connected between any two-phase conductors. One of these phases may have a grounded center conductor brought out, if required, to serve a 1O-2W, 120-volt load. Provision for a 1O-2W, 120-volt load can also be made external to the generator by using a center-tapped transformer.

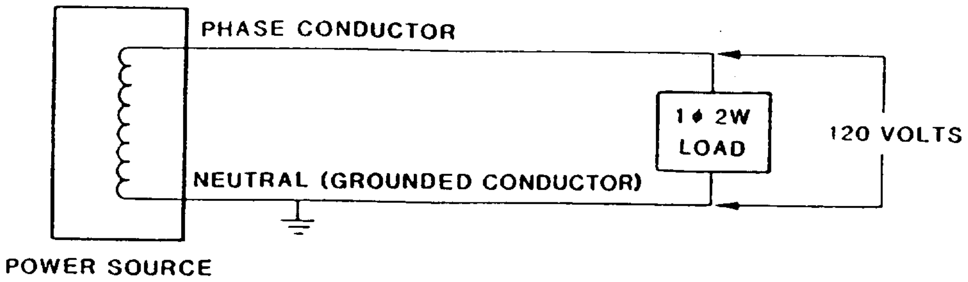


FIGURE A-8. Single-phase ac power.

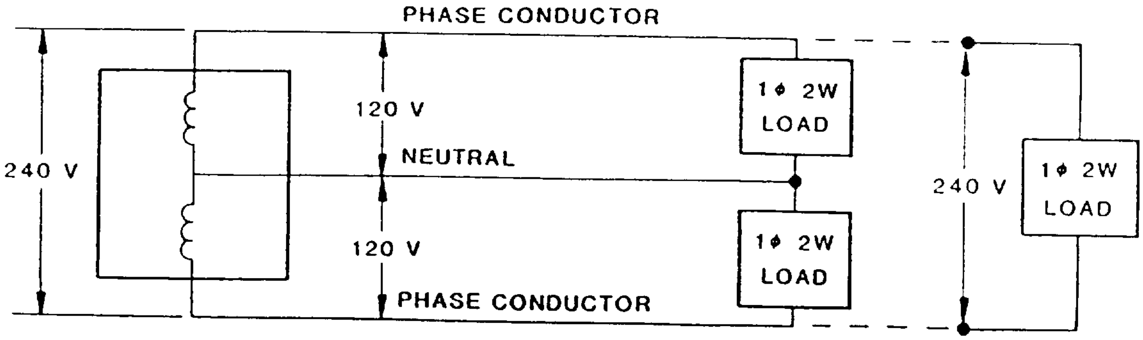


FIGURE A-9. Single-phase, three-wire ac power.

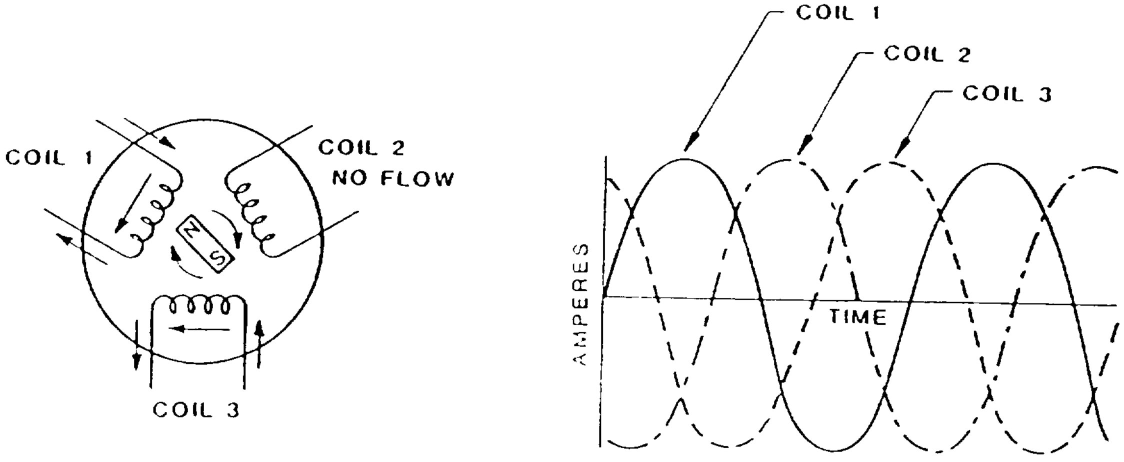


FIGURE A-10. Three phase power generation.

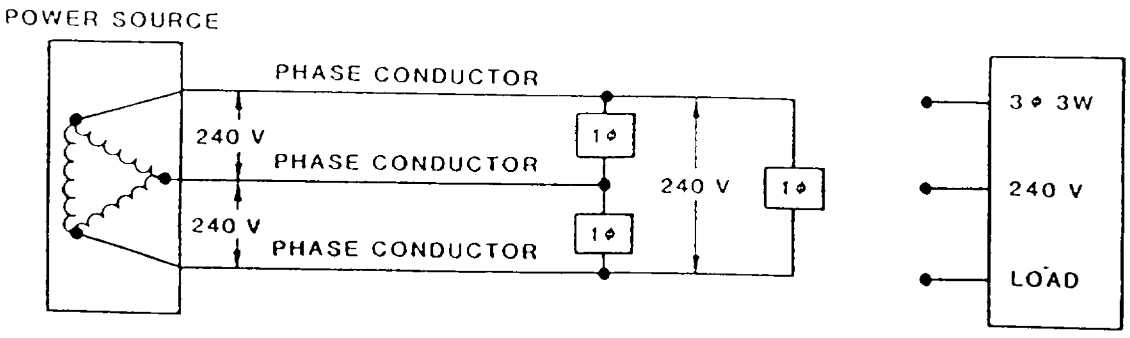


FIGURE A-11. Delta connected three-phase power.

c. Four-wire systems (30-4W). Figure A-12 snows a three-phase, four-wire system using a Y connection. There are two voltages simultaneously available from this system: phase-to-neutral voltage and phase-to-phase voltage. Note that the phase-to-phase voltage is equal to 1.73 times the phase-to-neutral voltage (208/120V). As in the single-phase system, the loads between the neutral and the phase wires should be balanced to reduce the current in the neutral to a minimum. Any 10-2W, 120-volt load can be fed power by connecting it between any phase conductor and the neutral. Any 10-2W, 208-volt load can be fed between any two-phase conductors. Any 30-3W, 208-volt load can be fed by connecting it to the three-phase conductors or any 30-4W, 120/208-volt load can be fed power by connecting it to any four conductors. The delta-based connection is seldom used on low-voltaqe power distribution systems. There are several reasons for this, such as higher voltages to ground and poorer suppression of unwanted harmonics. The wye system must also use a fifth conductor which is an equipment protection (green-wire) grounding conductor required by the National Electric Code

40.14 Reasons for using ac power. One of the most important reasons for using ac power generation and distribution is that it can be readily changed by use of a transformer. With a transformer, a particular ac or varying voltage can be raised or lowered to the value required by the load. A basic transformer is relatively uncomplicated, as shown in figure A-13. In this case, a conductor of particular type and size is wound around part of an iron core to form the input or primary side. Another conductor selected and sized to provide the desired output characteristics is wound on another part of the core for a secondary winding.

a. When a voltage (also referred to as electromotive force or emf) is applied to the primary side, magnetic lines of force are created that cut across the secondary winding and result in an induced secondary voltage. For this action to continue, the voltage in the primary side must continue to change in value or reverse in polarity. When the voltage reverses, a voltage of opposite polarity appears in the secondary winding.

b. The ratio of the number of turns in the primary and secondary windings determine whether a transformer is a voltage step-up or step-down device. Since the primary and secondary power theoretically remains the same (except for such things as flux leakage and resistance losses), the secondary current must decrease as voltage increases or increase as voltage decreases. Transformers are required for load isolation and to match the voltages in the distribution system to those required by the load.

50. Power usage data collection.

50.1 DoD worksheets. DoD facility power system load tabulation worksheets may be used to estimate total power requirements and an estimate of backup or power conversion equipment loads. See figures A-14 and A-15.

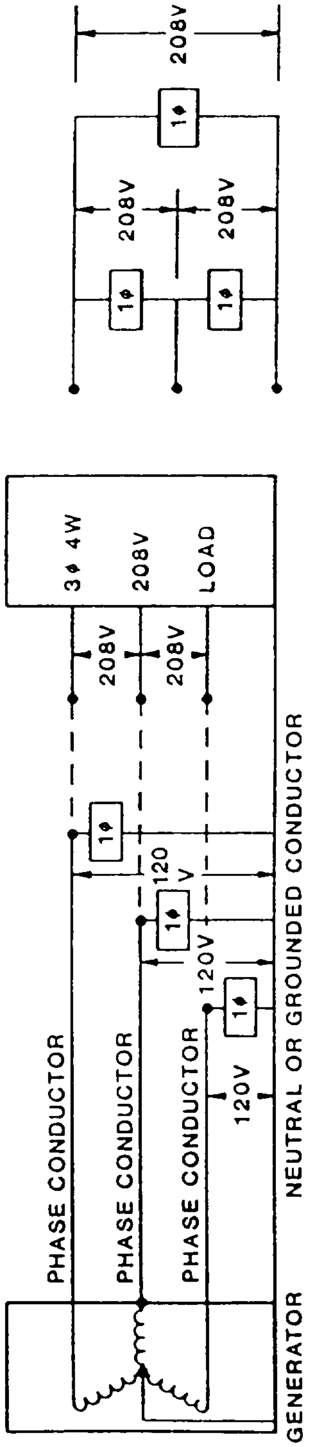


FIGURE A-12. Wye connection three-phase power.

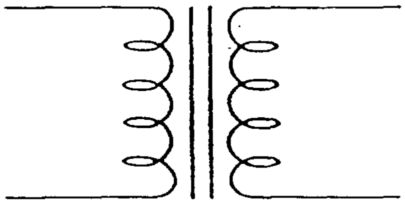


FIGURE A-13. Basic transformer configuration.

DoD FACILITY ELECTRICAL POWER SYSTEM LOAD TABULATION WORKSHEET*

FACILITY LOCATION ______
SUPPLY VOLTAGE ______ FREQUENCY ______ PHASE ______
SUPPLY SECONDARY TRANSFORMER CONNECTION DELTA ______ WYE ______

ITEM #	FUNCTIONAL DESCRIPTION OF STATION LOAD**	POWER FREQ REQ'D IF OTHER THAN 60 Hz	POWER HEIRARCHY DESIGNATION				BRANCH FEEDER #	PHASE		PHASES USED	TYPE OF BACKUP OR POWER CONVERSION EQUIPMENT REQUIRED (IN kW)						NOTES
											1	2	3	4	5	6	
			NO	NT	NCT	CT		1φ	3φ		NONE	ENGINE-GENERATOR	MOTOR-GENERATOR	STANDBY UPS	ON-LINE UPS	REDUNDANT OR PARALLEL UPS	
										TOTALS							TOTAL EST POWER

* SEE 50.2 OF APPENDIX A FOR SUGGESTED PROCEDURE

** IF LOAD IS AN ELECTRICAL MOTOR, OBTAIN DATA BY USING SHEET 2.

LEGEND: NO NON-OPERATIONAL NT NON-TECHNICAL NCT NON-CRITICAL TECHNICAL CT CRITICAL TECHNICAL

PAGE ______ OF ______

FIGURE A-14. Example DoD facility electrical power system load tabulation worksheet.

DoD FACILITY LOAD TABULATION WORKSHEET FOR ELECTRIC MOTORS

ITEM # FROM WORKSHEET 1	NAMEPLATE MOTOR INFORMATION				STARTING LOAD *			CONTINUOUS LOAD (RUNNING /STATIC)					NOTES
	HP	NEMA CODE	#	VOLTS	kVA	PF	kW **	VOLTS	AMPS	kVA	PF	kW	

LOCKED ROTOR LOAD PER MANUFACTURER OR TABLE A-4

** (LRkVA CAN BE DETERMINED BY USING LOCKED ROTOR AMPERES FOR SINGLE PHASE BY kVA= $\frac{\text{VOLTS X AMPERES}}{1000}$ OR FOR 3-PHASE BY kVA . $\frac{\text{VOLTS X AMPERES x}\sqrt{3}}{1000}$)

PAGE — OF —

FIGURE A-15. Example facility load tabulation worksheet for electrical motors.

50.2 Sizing procedures. The suggested steps for sizing the facility power load are:

a. Serially number and describe all facility power loads. List in the order most convenient for data collection and use as many sequentially numbered sheets as needed.

b. List power frequency required if other than 60 Hz.

Establish power hierarchy designation for the particular load (see 4.2.10 volume I).

d. Indicate branch feeder number when assigned.

e. Indicate phases required by the load and, when assigned, show phase A, B,C, as appropriate.

f. Enter power consumption of the load in kW in columns 1 through 6, as appropriate. It is important to accurately determine real power consumed. Since inductive loads, such as electric motors, typically represent a low power factor, sheet 2 (DoD facility load tabulation worksheet for electric motors), should be used to determine the kW figure to be entered on sheet 1. The power factor of switch-mode power supplies can also be low. If the manufacturer has not incorporated automatic power factor correction *in* his design, he must be asked to provide consumption data.

g. Care must be exercised in obtaining total estimated power consumption - this figure will normally be the total of columns *1* and 2. The individual totaling of columns 3 through 6 assists in sizing power conditioning equipment.

h. The determination of engine-generator set(s) size (column 2) is not a simple problem because load shedding, sequencing, simultaneous starts, etc., are all factors. The data obtained, after considering all the factors, may also be used to determine transfer switch size and rating. Final selection of engine-generator set size must also include a factor for future load increases.

60. Useful power conversions and tables. The information in tables A-1 through A-VII is intended for use in the facility planning phase to estimate loads, voltage drops, etc. Following equipment selection, the manufacturer should be consulted for exact specifications. The tables concerning sizing of electrical distribution conductors are for quick reference and should be compared with the current version of the National Electric Code (NEC) before a final selection is made.

TABLE A-1. Electrical] formulas for determining watts, kilowatts, amperes, kilovolt-amperes, and horsepower.

$$\text{Torque in lb-ft} = \frac{\text{hp} \times 5{,}250}{\text{rpm}} \qquad \text{hp} = \frac{\text{Torque} \times \text{rpm}}{5.250}$$

$$\text{rpm} = \frac{120 \times \text{frequency}}{\text{no. of poles}}$$

Where:

hp = horsepower
rpm = resolutions
p = number of poles

ELECTRICAL FORMULAS

To find	Alternating current three-phase
kVA	$\frac{1.73 \times I \times E}{1{,}000}$
Amperes when horsepower is known	$\frac{hp \times 746}{1.73 \times E \times Eff \times PF}$
Amperes when kilowatts are known	$\frac{kW \times 1{,}000}{1.73 \times E \times PF}$
Amperes when kVA is known	$\frac{kVA \times 1{,}000}{1.73 \times E}$
Kilowatts	$\frac{1.73 \times I \times E \times PF}{1{,}000}$
Horsepower (output)	$\frac{1.73 \times I \times E \times Eff \times PF}{746}$

I = Amperes
E = volts
Eff = Efficiency
hp = horsepower

kVA = Kilovolt-Amperes
kW = Kilowatts
PF = Power factor

TEMPERATURE CONVERSION

Degree C = (Degree F - 32) x 5/9
Degree F = (Degree C x 9/5) + 32

TABLE A-1. Electrical formulas for determining watts, kilowatts, amperes, kilovolt -amperes, dnd horsepower - continued.

Rules of thumb

At 3600 rpm, a motor develops 1.5 lb-ft per hp.
At 1800 rpm, a motor develops 3 lb-ft per hp.
At 1200 rpm, a motor develops 4.5 lb-ft per hp.
At 550 and 575 volts, a 3-phase motor draws 1 amp per hp.
At 440 and 460 volts, a 3-phase motor draws 1.25 amp per hp.
At 220 and 230 volts, a 3-phase motor draws 2.5 amps per hp.

$$\text{Voltage tolerance } \% = \frac{\text{No load-full load voltage}}{\text{x rated voltage}} \text{ X } 100$$

$$\text{Voltage regulation } \% = \frac{\text{No load-full load voltage}}{\text{full load volts}} \text{ X } 100$$

$$\text{Speed regulation } \% = \frac{\text{No load-full load}}{\text{full load speed (rpm)}} \text{ X } 100$$

OHM’s LAM: Ohm’s law states that the current in an electric circuit is equal to the pressure (voltage) divided by the resistance. This can be expressed by the equation:

$$\text{amperes} = \frac{\text{volts}}{\text{ohms}}$$

The equations may be written:

DC OHM’S LAW: $E = I \times R$ $\quad I = \frac{E}{R}$ $\quad R = \frac{E}{I}$

AC OHM’S LAM: $E = IZ$ $\quad I = \frac{E}{Z}$ $\quad Z = \frac{E}{I}$

Where:

E = volts
F = frequency

I = amperes
R = resistance (ohms)
Z = impedance (ohms)

TABLE A- II. Approximate ampere ratings of ac generators.

POWER FACTOR			SINGLE PHASE		THREE PHASE		
80%		Unity	120-V	120-/240-V	120-/208-V	120-/240-V	240-/480-V 277-/480-1
kW	kVA	kW-kVA	amp	amp	amp	amp	amp
10.0	12.5	12.5	104	52	35	30	15
12.5	15.6	15.6	130	65	43	38	19
		15.0	125	63	42	36	18
15.0	18.75	18.75	156	78	53	45	23
		17.5	146	73	49	42	21
17.5	21.87	21.87	182		61	53	26
		20.0	167	84	56	48	24
20.0	25.0	25.0	208	104	70	60	30
25.0	31.25		260	130	87	75	38
				125	83	72	36
30.0	37.5			156	104	90	45
35.5	43.75			182	122	105	53
40.0	50.0			208	139	120	60
45.0	56.25			234	156	135	68
50.0	62.5			260	174	151	75
55.5	68.75			286	191	166	83
60.0	75.0			313	209	181	90
65.0	81.25			339	226	196	
70.0	87.5			365	244	210	105
75.5	93.75			390	261	226	113
80.0	100.0			417	278	240	120
85.0	106.25			443	295	256	128
90.0	112.5			468	312	271	135
100.0	125.0			520	348	300	150
110.0	137.50			573	382	332	166
115.9	143.75			595	400	346	173
125.0	156.25			651	435	376	188
140.0	175.0			729	486	421	211
150.0	187.5				521	452	226
155.0	193.75				538	468	234
165.0	206.25				575	498	248
170.0	212.5				591	513	256
175.0	218.75				609	527	263
190.0	237.5				660	573	286
200.0	250.0				696	602	300
230	287.5				799	693	346
250	312.5				867	751	376
300	375				1042	903	452
350	437.5				1215	1054	527
400	500				1390	1204	602
450	562.5				1560	1354	676
500	625.0				1734	1500	751

NOTE: Always use kVA ratings when shown or known.

TABLE A-III. Typical running current requirements of motors.

HP	120 V 1-Phase ac		240 V 1-Phase ac		240 V 3-Phase ac		115 Vdc		230 Vdc	
	C	W	C	W	C	W	C	W	C	W
1/6	4.4	14	2.2	14						
1/4	5.8	14	2.9	14			2.9	14		
1/3	7.2	14	3.6	14			3.6	14		
1/2	9.8	14	4.9	14	2.0	14	5.2	14	2.6	14
3/4	13.8	12	6.9	14	2.8	14	7.4	14	3.7	14
1	16.0	12	8.0	14	3.8	14	9.4	14	4.7	14
1-1/2	20.0	10	10.0	14	5.2	14	13.2	12	6.6	14
2	24	10	12.0	14	5.8	14	17.0	10	8.5	14
3	34	6	17.0	10	9.6	14	25.0	8	12.2	12
5	56	4	28.0	8	15.2	12	40.0	6	20.0	10
7-1/2	80	1	40.0	6	22.0	10	58.0	3	29.0	8
10	100	0	50.0	4	28.08	8	76.0	2	38.0	6

C = Full rated current in amperes (amperes while starting are much higher).
W = Minimum wire size permitted by code; larger sizes often required - check distance for voltage drop.

TABLE A-IV. Locked-rotor current conversion table for motor circuits and controllers.

MAX. HP RATING	Typical motor locked-rotor current (in amperes)					
	SINGLE-PHASE		TWO- OR THREE-PHASE			
	120 V	240 V	120 V	208 V	240 V	480 V
1/2	58.8	29.4	24	14	12	6
3/4	82.8	41.4	33.6	19	16.8	8.4
1	96	48	42	24	21	10.8
1-1/2	120	60	60	34	30	15
2	144	72	78	45	39	19.8
3	204	102		62	54	27
5	336	168		103	90	45
7-1/2	480	240		152	132	66
10	600	300		186	162	84
15				276	240	120
20				359	312	156
25				442	384	192
30				538	468	234
40				718	624	312
50				862	750	378

TABLE A-V. Recommended wire size (AWG) for a three -pnase motor.

	HORSEPOWER									
VOLTS	1-3	5	7-1/2	10	15	20	25	30	40	50
208	14	10	8	6	4	3	1	0	000	000
240	14	12	10	8	6	4	3	1	0	000
480	14	14	14	12	10	8	6	6	4	3

TABLE A-VI. Characteristics of conductors.

CARRYING CAPACITIES (30 °C 86 °F)						
				In raceway or cable	In free air	
Wire size	Area (Circular mills)	ohms per 1000 ft. (25 °C or 77 °F)	Bare Copper (Pounds per 1000 ft.)	Rubber covered (Type R)	Rubber covered (Type R)	Weather proof (Type WP)
14	4,109	2.575	12.43	15	20	30
12	6,520	1.619	19.77	20	25	40
10	10,380	1.018	31.43	30	40	55
8	16,510	.641	49.98	40	55	70
6	26,240	.410	79.46	55	80	100
4	41,740	.259	126.4	70	105	130
2	66,360	.162	205.0	95	140	175
1	83,690	.129	258.9	110	165	205
0	105,560	.102	326.0	125	195	235
00	133,080	.0811	411.0	145	225	275
000	167,770	.0642	518.0	165	260	320
0000	211,600	.0509	640.5	195	300	370

TABLE A-VII. Wire sizes for 120-volt-dc or -ac unity power factor, 2-percent voltage drop (2.4 volts).

WATTS (Note 2)	AMPERES AT 120 VOLTS (Note 3)	WIRE SIZE (AWG) 14	12	10	8	6	4	2
		ALLOWABLE DISTANCE (feet) (Note 1)						
100	.84	550	880	1330	2080	3400	5500	8500
Zuo	1.67	275	440	665	1060	1690	2750	4300
30U	2.50	183	290	450	710	1130	1850	2840
400	3.33	137	220	330	530	840	1380	2150
500	4.16	110	175	265	430	680	1100	1700
750	6.25	73	115	177	285	450	740	1140
1000	8.33	55	83	130	214	340	550	850
1500	12.50	36	57	88	146	225	365	575
2000	16.60	27	42	68	104	166	275	430
25U0	20.80	22	37	52	83	135	220	365
3UJ0	25.00	18	26	42	68	115	188	285
3500	29.20		23	37	63	94	155	245
4000	33.30		21	31	52	83	134	217
4500	37.50		15	29	46	73	119	176
5000	41.80			26	42	67	108	166
6000	50.00			21	36	57	88	140
7000	58.30				29	46	78	119
8000	66.60				26	42	67	104
9000	75.00					36	57	93
10000	83.30					31	52	83

NOTES:

1. Figures represent a one-way distance in feet for a two-wire run. If a 4-percent voltage drop is permissible, double the distances listed.

2. For other voltages (120, 240, etc.), use the amperes column - disregard the watts column. If only a l-percent voltage drop is allowable, divide the distances listed by 2.

3. For 240-V and 480-V circuits, the information in the table cart be used if distances are changed as follows:

TABLE A-VII. Wire sizes for 120-volt-dc or -ac unity power factor, 2-percent voltage drop (2.4 volts) - continued.

a. For single-phase ac circuits:

Using watts - 4 x distance for 240 volts
16 x distance for 480 volts

Using amps - 2 x distance for 240 volts
4 x distance for 480 volts

b. For three-phase ac circuits (assuming a balanced three-phase load):

Using amperes - 4 x distance for 240 volts
8 x distance for 480 volts

Formula for determining wire size under any other condition:

a. Direct current and single-phase systems:

$$CM = \frac{D \times I \times 22}{td}$$

b. Three-phase, three-wire systems:

$$CM = \frac{D \times I \times 19}{Ed}$$

Where:

CM = Circular mills - wire size (see table VI)

I = Current in amperes (in the case of three-phase, it is the current in each wire)

D = Single distance (one-way length) of the circuit in feet

Ed = Allowable voltage drop in volts (2 percent of 115 volts is 2.3 volts, etc.)

TABLE A–VIII. Units, constants, frequency spectrum, and conversion factors.

A. Conversion factors.

TO CONVERT	TO	MULTIPLY BY	CONVERSELY, MULTIPLY BY
Ampere-hours	Coulombs	3,600	2.778 X 10^{-6}
Atmospheres	millimeters of mercury, 0° C	760	1.32 x 10-^{3}
Atmospheres	inches of mercury, 0° C	29.92	3.34 x 10-^{2}
Atmosphere	pounds of mercury, O^{o}C	14.7	6.8 x 10-2
Atmosphere	kilopascals	101.3	9.87 x 10-3
Btu (British thermal unit)	Footpounds	778.3	1.285 X 10^{-3}
Ecu	Joules	1,054.8	9.48 X 10^{-4}
Btu	Kilogram-calories	.252	3.969
Btu	Horsepower-hours	3.929 x 10^{-4}	2,545
Centigrade	Fahrenheit	(C^{0} x 9/5) + 32	(F^{0}- 32) X 5/9.
Centigrade	Kelvin	add 273	subtract 273
Circular mils	Square centimeters	5.067 x 10^{-6}	1.973 x 10^{5}
Circular mils	Square mils	.7854	1.273
Cubic inches	Cubic centimeters	16.39	6.102 X 10^{-2}
Cubic inches	Cubic feet	5.785 x 10^{-4}	1,728
Cubic inches	Cubic meters	1.639 X 10^{-5}	6.102 X 10^{4}
Cubic meters	Cubic feet	35.31	2.832 X 10^{-2}
Cubic meters	Cubic yards	1.308	.7646
Degrees (angular measure)	Radians	.01745	57.2958
Dynes	Pounds	2.248 x 10-^{6}	4.448 X 10^{5}
Ergs	Foot-pounds	7.367 x 10-^{8}	1.356 X 10^{7}
Foot-pounds	Horsepower-hours	5.05 x 10-^{7}	1.98 X 10^{6}
Foot-pounds	Kilogram-meters	.1383	7.233
Foot-pounds	Kilowatt-hours	3.766 x 10-^{7}	2.655 x 10^{6}
Grams	Dynes	980.7	1.02 x 10-^{3}
Grams	Ounces (avoirdupois)	3.527 x 10^{-2}	28.35
Grams per cm	Pounds per inch	5.6 **x** 10^{-3}	178.6
Grams per cubic cm	Pounds per cu. inch	3.613 x 10^{-2}	27.60

TABLE A-VIII. Units, constants, frequency spectrum, and conversion factors - Continued.

TO CONVERT	TO	MULTIPLY BY	CONVERSELY, MULTIPLY BY
Grams per sq. cm	Pounds per sq. foot	2.0481	.4883
Horsepouer (550 ft.-lb. per sec.)	Foot-lb. per minute	3.3 x 10^{4}	3.03 x 10^{-5}
Horsepower (550 ft.-lb. per sec.)	Btu per minute	42.41	2.357 x 10^{-2}
Horsepower (500 ft.-lb. per sec.)	Kg-calories per minute	10.69	9.355 x 10-^{2}
Horsepower (550 ft.-lb. per sec.)	Kilowatts	0.7457	1.341
Horsepower (Metric) (542.5 ft.-lb. per sec.)	Horsepower (550 ft.-lb. per sec)	.9863	1.014
Joules	Foot-pounds	.7376	1.356
Joules	Ergs	10^{7}	10^{-7}
Kilogram-calories	Kilojoules	4.186	.2339
Kilograms	Pounds (avoirdupois)	2.205	.4536
Kg per sq. meter	Pounds per sq. foot	.2048	4882
Kilowatt-hours	Btu	3,413	2.93 x 10^{-4}
Kilowatt-hours	Foot-pounds	2.655 x 10^{6}	3.766 x 10^{-7}
Kilowatt-hours	Joules	3.6 x 10^{6}	2.778 x 10^{-7}
Kilowatt-hours	Kilogram-caiories	860	1.163 X 10^{-3}
Kilowatt-hours	Kilogram-meters	3.671 x 10^{5}	2.724 X 10^{-6}
Liters	Cubic meters	.001	1,000
Liters	Cubic Inches	61.02	1.639 X 10^{-2}
Liters	Gallons (liq. US)	.2642	3.785
Liters	Pints (liq. US)	2.113	.4732
Poundals	Dynes	1.383 x 10^{4}	7.233 x 10^{-5}
Poundals	Pounds (avoirdupois)	3.108 x 10-*	32.17
Radians	Degrees	57.2958	.01745
Sq inches	Circular mils	1.273 x 10^{6}	7.85.4 x 10^{-7}
Sq inches	Sq centimeters	6.452	.155
Sq feet	Sq meters	9.29 x 10-2	10.76
Sq miles	Sq yards	3.098 x 10^{6}	3.228 x 10^{-7}
Sq miles	Sq kilometers	2.59	.3861

TABLE A-VIII. Units, constants, frequency spectrum, and conversion factors - Continued.

TO CONVERT	TO	MULTIPLY BY	CONVERSELY, MULTIPLY BY
Sq millimeters	Circular mils	1.973	5.067×10^{-4}
Tcns, short (avoir 2,000 lb.)	Tonnes (1,000 Kg.)	.9072	1.102
Tons, long (avoir 2,240 lb.)	Tonnes (1,000 Kg.)	1.016	.9?342
Tons. long (avoir 2.240 lb.)	Tons, short (avoir 2,000 lb)	1.120	.8929
Watts	Btu per min	5.689×10^{-2}	17.58
Watts	Ergs per sec	10^{7}	10-7
Watts	Ft-lb per minute	44.26	2.26×10^{-2}
Watts	Horsepower (550 ft-lb per sec.)	1.341×10^{-3}	745.7
Watts	Horsepower (metric) (542.5 ft-lb per sec.)	1.36×10^{-3}	735.5
Watts	Kg-calories per min	1.433×10^{-2}	69.77

B. Luminance conversion factors.

1 nit = 1 candela/square meter
1 stilb = 1 candela/square centimeter
1 apostilb (international) = 0.1 millilambert = 1 blondel
1 apostilb (German Hefner) = 0.09 millilambert
1 lambert = 1,000 millilamberts

Multiply number of by ↘ To obtain number of	footlambert	candela per sq meter	millilambert	candela/sq in	candela per sq ft	stilb
footlambert	1	0.2919	0.929	452	3.142	2,919
candela/sq m	3.426	1	3.183	1,550	10.76	10,000
millilambert	1.076	0.3142	1	487	1.382	3,142
candela/sq in	0.00221	0-000645	0.00205	1	0.00694	6.45
candela/sq ft	0.3183	0.0929	0.2957	144	1	929
stilb	0.00034	0.0001	0.00032	0.155	0.00108	1

TABLE A-VIII. Units, constants, frequency spectrum, and conversion factors - Continued.

C. Conversion factors for units of length.

Multiply number of by to obtain number of	Angstroms	Nanometers	Micrometers	Millimeters	Centimeters	Meters	Kilometers	Mils	Inches	Feet	Miles
Angstroms	1	10	10^4	10^7	10^8	10^{10}	10^{13}	2.540×10^5	2.540×10^8	3.048×10^9	1.609×10^{13}
Nanometers	10^{-1}	1	10^3	10^6	10^7	10^9	10^{12}	2.540×10^4	2.540×10^7	3.048×10^8	1.609×10^{12}
Micrometers (Microns)	10^{-4}	10^{-3}	1	10^3	10^4	10^6	10^9	2.540×10	2.540×10^4	3.048×10^5	1.609×10^9
Millimeters	10^{-7}	10^{-6}	10^{-3}	1	10	10^3	10^6	2.540×10^{-2}	2.540×10	3.048×10^2	1.609×10^6
Centimeters	10^{-8}	10^{-7}	10^{-4}	10^{-1}	1	10^2	10^5	2.540×10^{-3}	2.540	3.048×10	1.609×10^5
Meters	10^{-10}	10^{-9}	10^{-6}	10^{-3}	10^{-2}	1	10^3	2.540×10^{-5}	2.540×10^{-2}	3.048×10^{-1}	1.609×10^3
Kilometers	10^{-13}	10^{-12}	10^{-9}	10^{-6}	10^{-5}	10^{-3}	1	2.540×10^{-8}	2.540×10^{-5}	3.048×10^{-4}	1.609
Mils	3.937×10^{-6}	3.937×10^{-5}	3.937×10^{-2}	3.937×10	3.937×10^2	3.937×10^4	3.937×10^7	1	10^3	1.2×10^4	6.336×10^7
Inches	3.937×10^{-9}	3.937×10^{-8}	3.937×10^{-5}	3.937×10^{-2}	3.937×10^{-1}	3.937×10	3.937×10^4	10^{-3}	1	12	6.336×10^4
Feet	3.281×10^{-10}	3.281×10^{-9}	3.281×10^{-6}	3.281×10^{-3}	3.281×10^{-2}	3.281	3.281×10^3	8.333×10^{-5}	8.333×10^{-2}	1	5.280×10^3
Miles	6.214×10^{-14}	6.214×10^{-13}	6.214×10^{-10}	6.214×10^{-7}	6.214×10^{-6}	6.214×10^{-4}	6.214×10^{-1}	1.578×10^{-8}	1.578×10^{-5}	1.894×10^{-4}	1

FIRE PROTECTION

10. Scope. Damage from fires (and the consequent disruption of operations) can be minimized by the installation of appropriate fire protection systems. The system, or systems (more than one might be necessary), must protect the entire facility and must be of a type appropriate to the facility. The wrong type of system can, like the fire itself, be a threat to the facility. For example, an automatic water sprinkling system can damage electronic equipment, and would be inappropriate for a communications or data processing facility. Often, it is necessary to employ several different types of systems at a given facility. Systems commonly used at DoD facilities include the following:

20. Applicable documents. MIL-HDBK-1008, Fire Protection For Facilities Engineering, Design, and Construction.

30. Halon 1301 systems. Halon is a colorless, odorless, nonconductive gas (bromotriflouromethane), which when released in a confined area, extinguishes fires by inhibiting the chemical reaction between fuel and oxygen. It is used in place of CO_2 systems because of the extreme personnel safety hazard created by use of CO_2 in confined spaces. There are two types of Halon 1301 systems used at fixed installations: (1) total flooding, and (2) local application. The total flooding system is designed to cover a large area, and would normally be the system used in a computer facility. The local application system focuses on a single point which may be a critical fire hazard such as flammable liquids or other highly combustible materials. Both systems consist of: (1) a pressurized tank with a control valve that may be electrically or manually activated, (2) automatic detection devices, (3) dispersion heads, and (4) an electronic monitor and control panel. Figure B-1 shows a typical Halon 1301 System.

30.1 Design of facilities using Halon systems. Design of the facility is important if a Halon 1301 system is to be used for fire Protection. It is essential that the protected area be constructed with minimal openings so the Halon, if released, cannot escape from that area. Windows should be of a type that cannot be opened. All doors should have weatherstripping on the top and sides, with an adjustable door sweep at the bottom. Doors should also have automatic closers and signs on both sides stating that the door must remain closed at all times. All air-handling systems, to include heating, cooling, and ventilating systems, should be connected to the electronic control panel in such a way that all systems will shut down at the first indication of a fire alarm. This prevents air from being forced into the room and diluting the Halon, and also prevents the Halon from being removed from the protected area by return ducts or exhaust fans. Release of Halon may cause an electrostatic charge on ungrounded conductors; therefore, equipment must be grounded in accordance with MIL-HDBK-419. Floor coverings should also be of antistatic material. If an electrostatic charge is allowed to develop, it may reach a potential that could cause a discharge between two objects, which may cause an explosion. Positioning of detectors is also critical. Smoke detectors should be placed away from air conditioning vents which would tend to blow the smoke away from the detector. It is also

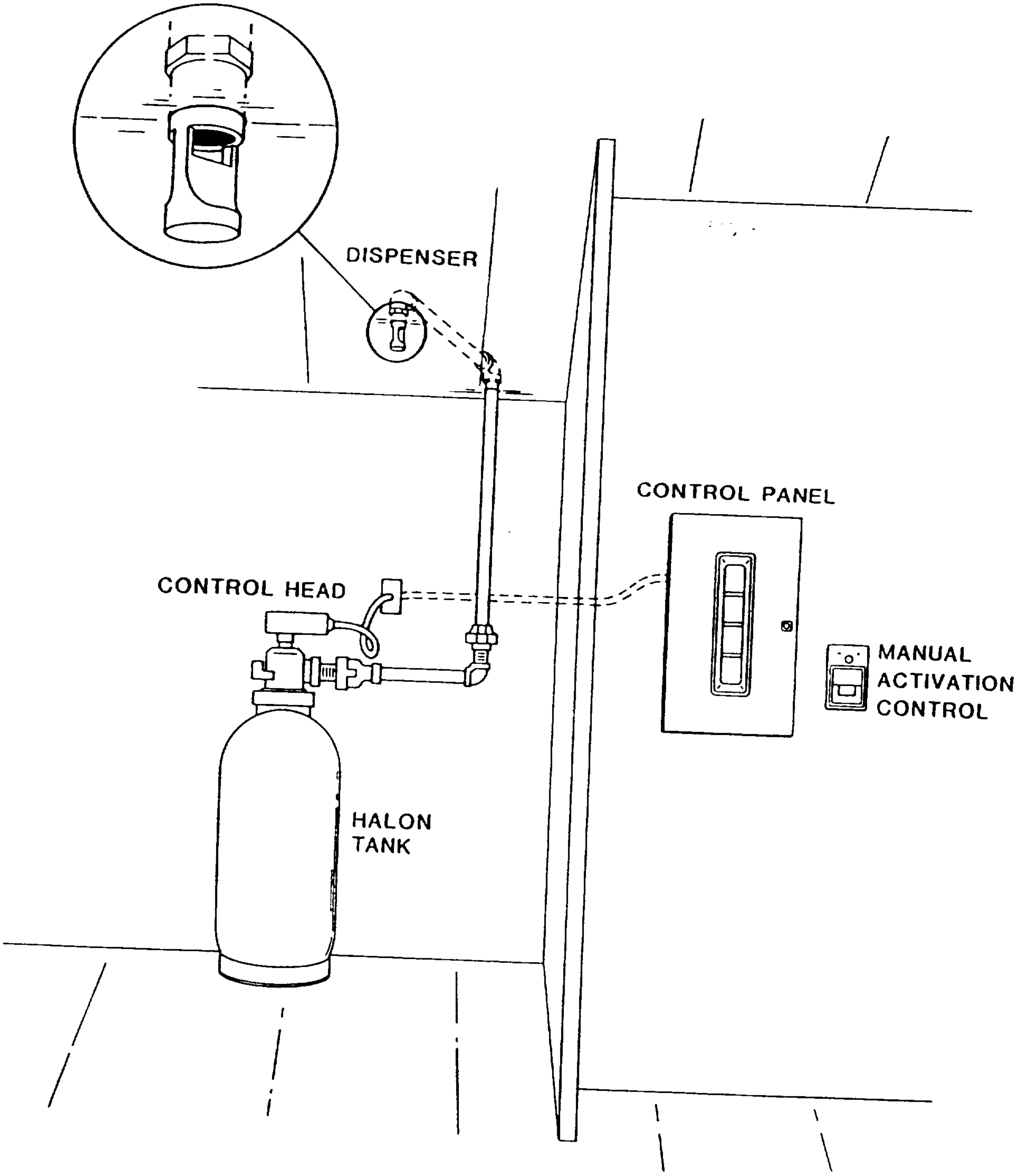


FIGURE B-1. Typical Halon 1301 System.

recommended that a smoke detector be placed near each return air duct and exhaust vent since smoke will naturally be drawn out of the room through these vents. This reduces detection time. Smoke and heat detectors should also be installed above ceilings and under raised floors. Detectors under raised floors should be positioned as shown in figure B-2.

30.2 Exposure of personnel to Halon. Exposure to Halon should be avoided whenever possible. There is not serious risk to personnel from exposure to Halon 1301 vapors for brief periods, but exposure for extended periods or to high concentrations may cause dizziness, impaired coordination, and irregular cardiac rhythm. Usually these symptoms disappear when the individual leaves the area, but continued exposure may be fatal. It has also been reported that Halon may cause damage to the earth's ozone layer.

40. Automatic water sprinkling systems. NFPA 13 requires automatic water sprinkllng systems to be installed in areas where highly combustible materials are usea *or* stored, or have been used in construction of a building. Other areas should be evaluated to determine if it is practical to install-such systems. When designing automatic water sprinkling systems, the following factors must be considered:

a. What is the possibility of fire in the area?

b. What combustible material is used or stored in the area, or was used in construction of the building?

c. Is the area protected by other systems such as a HaIon 1301 or an early warning system?

d. Is the equipment density in the area high or low?

e. Will unacceptable damage be caused if the water system is activated, either by a fire or accidentally?

If the likelihood of fire is low and equipment or material is susceptible to water damage, sprinkler systems should be avoided, and a Halon 1301 or an early warning system installed. It may be advisable to avoid sprinkler systems in areas where water pressure is low.

There are four types of automatic water sprinkling systems: (1) wet-pipe, (2) dry-pipe, (3) pre-action, and (4) deluge. Wet-pipe systems employ automatic sprinklers attached to pipes connected to a water supply. The pipes are filled and the sprinklers discharge water immediately when opened by heat of a fire. The dry-pipe system contains pressurized air or nitrogen. When the sprinklers are opened, as by heat of a fire, the gas pressure drops water pressure from the supply to open a valve, and water flows into the pipes to be dispensed from the sprinklers. The pre-action system employs automatic sprinklers connected to pipes containing air that may or may not be under pressure. A supplemental fire detection system is installed in the same area as the sprinkling system. When the detection system is activated, a valve opens, permitting water to flow into the pipes and to be discharged through the sprinklers (which have been opened by the fire). The deluge system is similar to the pre-action system, but uses open sprinklers instead of closed ones.

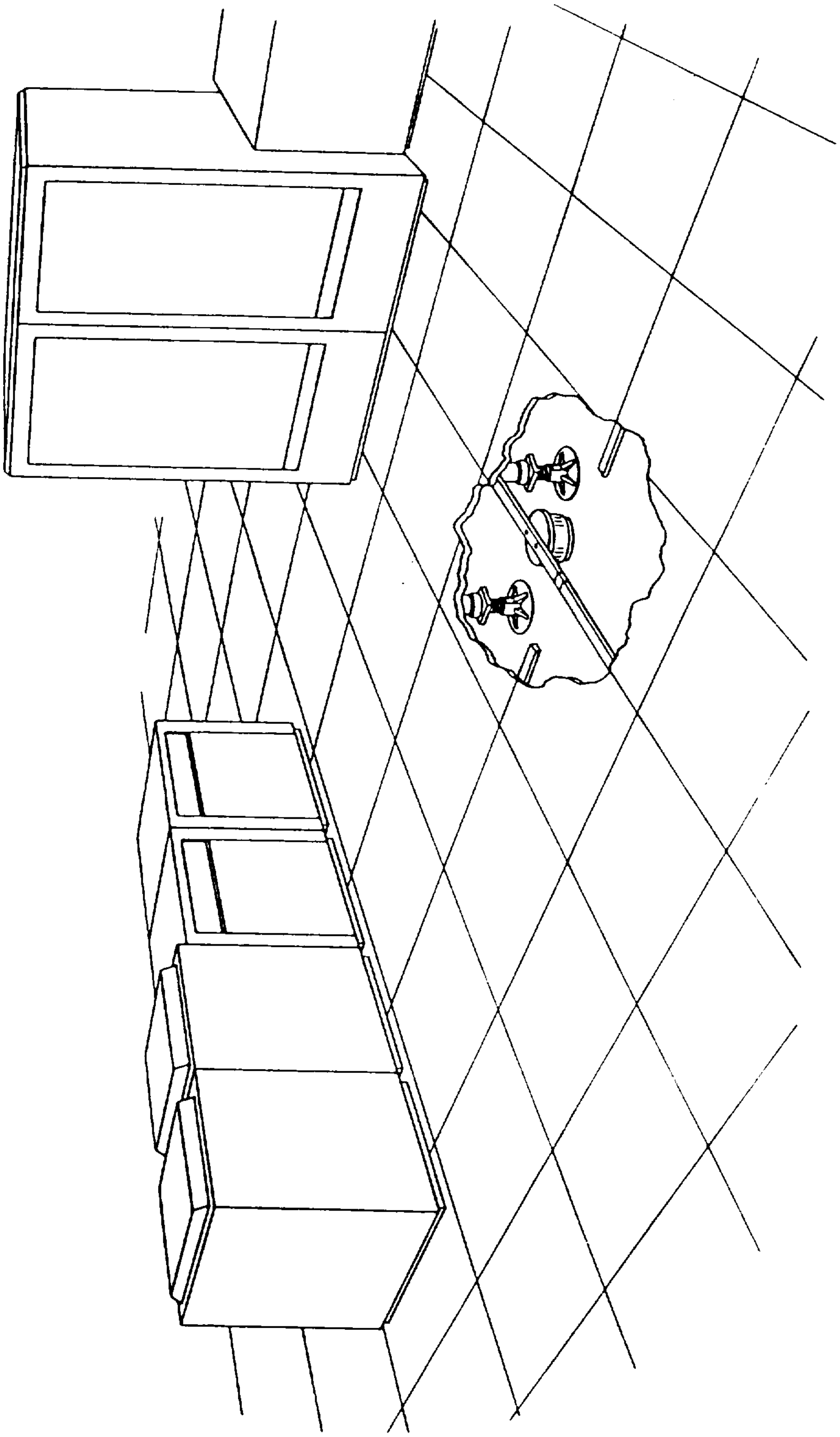


FIGURE B-2. Under-floor detector mounting.

40.2 Installation. When installing an automatic water sprinkling system, it is important to place the sprinklers so they will provide total, overlapping coverage of the protected area. If high objects block coverage of certain spaces within the protected area, additional sprinklers should be installed to provide total coverage. Because they are controlled and activated electronically, pre-action and deluge systems are preferable to other types of sprinkler systems. An electronic control panel should be installed in the protected area. This panel should be connected to the central control panel or monitor station, and should be equipped with an abort function so that water dumping could be prevented if the system should be accidentally activated. If a wet-pipe or dry-pipe system is used, there is little chance of stopping water dumping in the event of accidental activation.

50. Early Warning System. The early warning system is designed to provide fire protection in areas where use of an automatic water sprinkling system may damage a facility, and use of a Halon 1301 system is not warranted due to low equipment density. An early warning system consists of heat and smoke detectors, local audible and visual alarms, an electronic monitor and control panel, and a reliable means of communication. The heat and smoke detectors are designed to detect the earliest signs of smoke or unusual temperature rise. When the system is activated, the local alarms are energized, and a signal is automatically transmitted to a monitor station.

For this type of system to be effective: (1) the Communication link between the facility and the monitor station must be highly reliable. The desired reliability is 95 percent. Since this may not be attainable in some areas, the reliability should not be below 80 percent, and (2) the response time of the fire department after notification should be 5 minutes or less. If the response is more than 5 minutes, other protective systems should be considered.

The communication link may be a dedicated line through the local telephone exchange, an automatically dialed high-priority telephone circuit, or a radio link. When using either type circuit through the telephone exchange, 24 Vdc must be provided. This may be supplied by the facility central control panel or by the telephone exchange. When the system is activated, the polarity of the dc is reversed, triggering an alarm at the monitor station. The monitor station then notifies the support fire department.

When designing an early warning system, the first step is to determine the reliability of the communication link. Telephone exchange records for the last six months should be reviewed to determine the number and cause of outages, average downtime, and corrective action taken. If the period of time reviewed does not cover the period of peak thunderstorm activity in the area, the latter period should also be reviewed. If acceptable reliability cannot be achieved, an early warning should not be used. If a radio is to be used, it is important to determine if any equipment in the facility can interfere with and reduce the reliability of the radio link. It is also important to survey adjacent facilities and the line-of-sight path between the facility and the monitor station to identify other sources of potential interference (e.g., radio or television broadcast stations). Since the early warning system is usually used without a fixed fire extinguishing system, it is recownnended that portable fire extinguishers be strategically placed throughout the facility.

60. Detectors. The selection, positioning, and installation of detectors depends on facility design, equipment configuration, type of equipment, materials in the construction of the building used, and the anticipated fire potential. Usually a combination of heat, smoke, and flame detectors works better than one type of detector used alone. Typical detectors are shown in figures B-3a through B-3d.

60.1 Heat detectors. Heat detectors have the lowest false alarm rate, but are also the slowest in detecting fires. They are designed to activate a fire alarm when the temperature of their elements exceeds a fixed temperature rating (usually 135 °F (57 °C) or 200 °F (93 °C)). There are three common types of heat detectors: (1) eutectic (fusible) metal, (2) glass bulb, and (3) bimetal. The eutectic type uses alloys of bismuth, cadmium, lead, or tin for elements. These elements are designed to melt at the rated temperature, thus activating the alarm. This type is not restorable, and therefore must be replaced after it has been activated. The glass bulb detector is the least commonly used type. It consists of a switch which is normally open, a built filled with liquid under high pressure with a small bubble. When heated, the liquid expands and compresses the air bubble. When the air bubble has been totally absorbed, a rapid increase in pressure occurs and the bulb breaks, closing the switch and activating the alarm. There are two types of bimetal detectors: (1) the bimetal strip, and (2) the bimetal disc. Both types employ a switch consisting of two metals with different thermal expansion coefficients. When the metals are heated, the metal strip or disc with the higher expansion coefficient bends toward the one having the lower expansion coefficient. When the two pieces of metal contact each other, the alarm is activated. When the source of heat has been eliminated, the metals cool and separate, thus restoring the detector to normal monitoring condition. The strip detector, although effective, has a relatively slow response time. The disc type has a rapid response time and is more effective for early fire detection. A major disadvantage of bimetal detectors is that they often cause false alarms due to vibration. This is especially true as the room temperature approaches the threshold temperature of the detector.

60.2 Smoke detectors. There are two common types of smoke detectors: (1) photoelectric detectors, and (2) ionization detectors. Photoelectric detectors operate by sensing a change in the intensity of light received by a photo receptor. When smoke is present, light is reflected onto the light-sensitive photocell, causing its resistance to decrease. This causes an increase in current which is electronically amplified to produce an alarm voltage. The advantages of photoelectric detectors are: (1) fast response to smoldering fires, (2) fast response to smoke regardless of the distance smoke has travelled, (3) fast response to overheated pvc wire insulation, (4) insensitivity to air velocity, and (5) the ability to install in areas where control led fires are present or where nonflammable gases or vapors are normally found. Some disadvantages are slow response to: (1) fast-flaming fires, and (2) combustion particles having a diameter smaller than the wavelength of the light source.

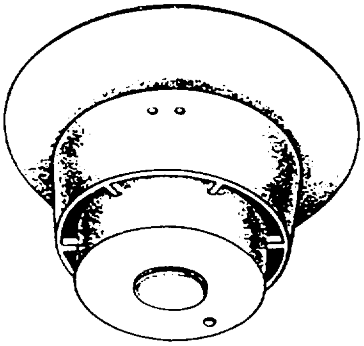


FIGURE B-1A PHOTOELECTRIC SMOKE DETECTOR

FIGURE B-3a. Photoelectric smoke detector.

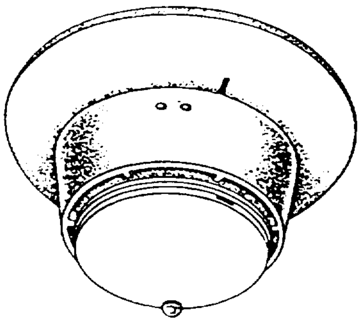


FIGURE B-1B IONIZATION SMOKE DETECTOR.

FIGURE B-3b. Ionization smoke detector.

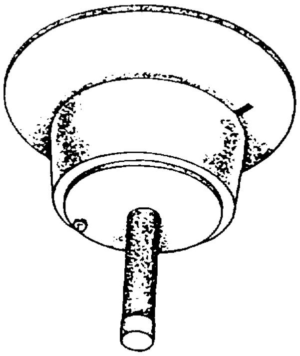


FIGURE B-1C HEAT DETECTOR

FIGURE B-3c. Heat detector

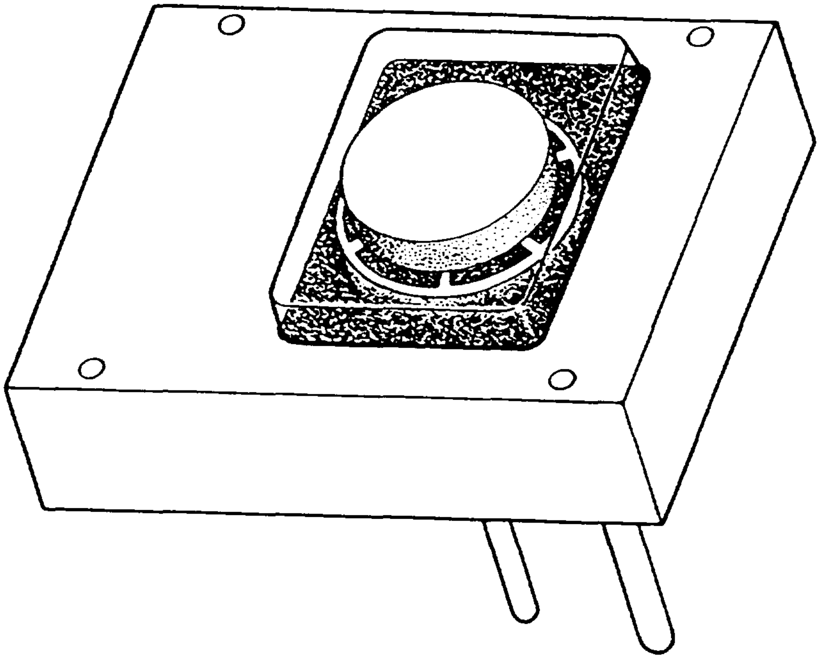


FIGURE B-3d. Duct detector.

60.3 Ionization detectors. Ionization detectors operate by sensing a change in the electrical properties of a chamber containing minute quantities of radioactive material. Alpha emissions from this material ionize the air between two plates. When combustion products from a fire enter the chamber, they change the impedance of the chamber, causing a voltage shift and triggering an alarm. The advantages of ionization detectors are: (1) quick response to fast-flaming fires, (2) quick response to fires that produce only a small amount of smoke and no visible flame, and (3) sensitivity to a wide range of combustion products. The disadvantages are: (1) slow response time to smoldering fires, (2) changes in sensitivity due to altitude or the presence of radiation sources in the environment, and (3) changes in sensitivity due to sudden changes in temperature, humidity, and barometric pressure. Many ionization detectors, however, employ designs to compensate for the effects of temperature, humidity, air pressure, altitude, etc.

60.4 Flame detectors. Flame detectors sense ultraviolet or infrared radiation produced by flames or glowing embers. Flame detectors have the fastest response time of all types of detectors, but, unfortunately also have a high false-alarm rate. Areas in which this type of detector is employed should be designated as nonsmoking. Care must be taken to ensure that no objects are positioned so that they can block the “vision” of the device. This type detector should be used only in areas of extremely high risk, such as fuel storage areas, and should not be used in operations or equipment areas.

60.5 Duct detectors. Duct detectors are typically smoke detectors which are installed inside air conditioning ducts. They should be placed close to possible sources of fire, such as fan motors or compressors.

70. Fire prevention. The most effective method of fire protection is prevention. construction materials should be flame retardant. In addition, wall, floor, or roof penetrations should be equipped with a fire-stop barrier to prevent flame or smoke from passing from one area to another. Foamed silicone elastomer is used to provide such a barrier, since it is fire resistant, stable at high temperatures, and easily installed. The foam is sprayed around the penetrations to provide a complete, air-tight seal. Since it is a two-part mixture, the silicone expands when the two parts are mixed, closing around the penetration. Additional treatment may be provided by spraying the foam inside floors, walls, and ceilings.

APPENDIX C

PHYSICAL SECURITY

10. Scope. The need for providing physical security depends on the geographical location and vulnerability of the facility and the criticality of the mission. Physical security measures may include access control, perimeter fences, perimeter lighting, closed circuit television (CCTV), and an intrusion detection system. This appendix provides general physical security guidelines.

20. Applicable documents. MIL-HDBK-1013/l , Design Guidelines For Physical Security of Fixed Land-Based Facilities.

30. Access control. There are numerous methods of providing access control . Among these methods are guard force, mechanical or electronic cipher locks, dial combination locks, key locks, and internally controlled electrical door releases. Recent developments in biometric access control can be used for access when permitted by individual service publications. Biometric access control is the method of identification and" verification in which the person seeking access is identified by fingerprints, palm pattern and geometry, retinal pattern, voice analysis, signature dynamics, and other methods.

30.1 Guard force. A guard force may be employed to provide access control. This method is quite effective, requiring some form of personal recognition or identification. Usually, access rosters are provided to guard personnel, listing all personnel who are authorized access to the facility. The guard is responsible to positively identify individuals and verify authorization. Since comparing identification by checking the access roster would be too time consuming in large facilities, a pass or badge system may be effective. Passes or badges should include a photograph of the individual to whom they are issued. They must be closely controlled and should be withdrawn when access is no longer authorized. Visitors to the facility should be issued a temporary badge or pass after formal identification has been provided, and the need for access established. Infrequent visitors should be accompanied by an escort (usually a person assigned to the facility) while in the facility. An access roster may be provided to guard personnel for frequent visitors to the facility. These personnel may be granted access as authorized by the local security manager.

30.2 Mechanical or electronic cipher locks. Cipher locks are combination locks which are opened by pushing a series of buttons or switches. A cipher lock may be used for access control during normal working hours or when the facility is manned. They should never be used to provide physical security for unmanned or part-time facilities. It should be noted that electronic cipher locks should be equipped with backup battery power to permit access during power outages.

30.3 Dial combination locks. This type lock is generally used on doors inside the facility and not on outside entrances. Group I dial combination locks provide a high degree of physical security and may be used when the facility is unmanned. This type lock is frequently used with a cipher lock. During the time that a facility is manned, the dial lock may remain open. Access would be controlled by the cipher lock.

30.4 Internally controlled electric door release. This type of access control may be used internally lt access to the entire facility is controlled. Access authorization must be verified when using this method. This may be done by using a guard inside an entrance to the controlled area to properly identify personnel.

40. Perimeter fencing. Perimeter fences may provide a high degree of access control. The distance from the facility that a fence is installed is dependent on the available real estate and the need for facility protection. The distance should be great enough to permit detection, prior to reaching the facilities, of personnel who have successfully penetrated the perimeter barrier. Chainlink fences are recommended and may be extended by installing three strands of barbed wire atop the fence. Fences should be a minimum of 8 feet high without barbed wire. All fence posts should be securely anchored *in* concrete to *prevent* removal or the fence being easily pushed over. All gates should be equipped with locking mechanisms and remain secured when not in use. Personnel access gates may be equipped with cipher locks but should have other locking mechanisms such as padlocks for periods of time when the facility is unmanned.

50. Perimeter lighting. The major function of perimeter lighting is to provide visibility of the area surrounding the facility during hours of darkness. When properly installed, lights may also be effective as a deterrent to attempted barrier penetration. It is important when designing a perimeter lighting system to use lights with rapid turn-on time and recovery time after power outages.

50.1 Types of perimeter lights. Among the types which may be used are incandescent, mercury vapor, fluorescent, tungsten-halogen, metal halide, high pressure sodium, and low pressure sodium.

TABLE C-1. Comparison of perimeter lighting types.

Lamp type	Lamp efficacy (Lumens per Watt)	Life (hours)
Incandescent	9-22	750-2,500
Fluorescent	45-95	7,500-20,000
Metal halide	80-115	7,500-15,000
High-pressure sodium	80-140	12,000-24,000

50.2 Installation practices. Exterior perimeter lighting may be installed by using direct or indirect illumination. Lights should be installed on or near the roof of the structure and should be positioned to provide total coverage of the areas surrounding the facility. If the lights are not adequate for providing light beyond the perimeter fence, if installed, lights should be installed on poles at the fence line to provide illumination for an adequate distance beyond the perimeter barrier. A safe distance may be defined as a minimum of 15 feet, but may be greater, depending on the terrain and threat of penetration. Indirect lighting involves installing lights away from the structure, pointing toward it. This will provide backlighting to easily detect intruders. If it is necessary to provide lighting beyond the perimeter, lights may be installed facing both directions, providing lighting from the perimeter to the facility and external to the perimeter barrier.

60. Closed circuit television (CCTV). This type system may be used for physical security inside and outside the facility. This system is particularly effective for monitoring hallways, doors, and perimeters. The CCTV system consists of a monitor station and cameras installed in strategic locations.

60.1 Monitor station. The monitor station should be located in an area within the facility which is out of the main personnel areas and provides adequate accessibility to the area protected by the system. Monitor stations may be configured with one monitor with a mechanism to select one camera at a time for viewing, or they may have a monitor for each camera. In high security facilities, the latter configuration is more effective.

60.2 Cameras. Cameras should be positioned to provide maximum coverage of the area to be monitored. When used to monitor open areas or as perimeter monitors, cameras should be spaced in such a way that the field of view overlaps that of adjacent areas to ensure complete coverage. Cameras should also be installed in a position where tampering is difficult. Additional protection should be provided by installing all power and signal cables for the system in conduit or duct. When cameras are used to monitor exterior perimeters or dimly lighted areas, additional lighting as specified by the manufacturer may be needed.

70. Intrusion detection system (IDS). An intrusion detection system may be used in facilities to provide additional protection. IDSs typically consist of magnetic switches and motion sensors. All exterior entrances, open areas, and sensitive areas within the facility should be protected. Motion sensors may be installed to provide general coverage of open areas to prevent an intruder from crawling under the area of coverage. Areas protected that require only periodic access should be armed at all times except when authorized access is necessary. The IDS should connect to a remoted monitor station through a dedicated line or autodial telephone line. This will aid in providing notification to the appropriate police or security agency. The IDS should be designed as specified in appropriate security documents.

APPENDIX D
CHECKLISTS

10. Scope. This appendix provides checklists for site survey engineering, power system evaluation, and energy conservation.

20. Applicable documents. This section is not applicable to this appendix.

30. Site survey engineering checklist.

Date: ______________

Name of Facility: ______________________ Location: ______________________

Person(s) completing checklist: ______________________________________

____

Identification

1. Has the facility been completely and accurately identified?

Latitude: ____________ Longitude: ____________ Elevation: ____________

Map Sheet Number: ____

Map Coordinates: __________________ Nearest City/Town: __________________

County/State/Country: ____

Weather

2. Has meteorological data for the site location been thoroughly researched? Use of triservice Engineering Weather Data Manual (TM 5-785. NAUFAC P-89, AFM 88-29) is mandatory within DoD.

a. Design temperatures.

(1) Summer dry bulb and wet bulb: ________________________________

____

(2) Winter dry bulb and wet bulb: ________________________________

____

b. Humidity conditions.

(1) Relative humidity (typical, by month): ________________________

____

c. Degree days.

(1) Heating: ______________________________

(2) Cooling: ______________________________

d. Precipitation.

(1) Rainfall (by month): ______________________________

____

(2) Snowfall (by month): ______________________________

____

(3) Ice fomation (by month): ______________________________

____

(4) Damaging hail potential (by month): ______________________________

____

e. Prevailing winds.

(1) Direction (by month): ______________________________

(2) Speed (by month): ______________________________

f. Solar radiation.

(1) Solar angle (by month): ______________________________

(2) Average daily hours of sunshine (by month): ______________________________

____

(3) Average intensity (Btu/hr x ft^2 or W/m^2) (by month): ____________

____

g. Lightning.

(1) Density (by month): ______________________________

(2) Unusual weather potential (monsoon, tornado, hurricane, sand storm) (by month): ______________________________

Geographical features.

3. Have important local geographical features which could affect building siting and design been identified and analyzed?

a. Hills and mountains (as they affect weather, radiation): ______________________________

b. Bodies of water (as they affect weather, provide floor potential, provide potable source, serve as heat sources or sinks): ______________________________

c. Vegetation (as it provides soil erosion protection, wind screening, blocking of solar radiation): ______________________________

d. Seismic activity: ______________________________

e. Vulnerability (as created by proximity to target areas, dangerous activities, hazardous materials, or other risks): ______________________________

f. Soil conditions: Has local soil been tested for construction, chemical, and electrical properties? ______________________________

On-site support.

4. Have on-site support capabilities been determined?

a. Power capability and reliability: see volume II, item 40, power checklist: ______________________________

____

b. Other utilities.

(1) Water supply (quality and quantity): ______________________________

____

(2) Sewage disposal: ______________________________

____

(3) Centralized heating/cooling plant: ______________________________

____

____

(4) Natural gas: ______________________________

____

c. Maintenance.

(1) Mission (other information systems activities which have repair and testing facilities): ______________________________

____

____

(2) Support (other DoD activities which have maintenance capabilities):

____

____

d. Communications.

(1) Voice (access to military and civilian networks): ____________________

____

____

(2) Data (access to military and civilian networks): ____________________

____

e. Transportation.

(1) Air: ____________________

(2) Ground: ____________________

(3) Sea: ____________________

f. Supply.

(1) parts/materials: ____________________

____

(2) Storage: ____________________

g. Housing.

(1) Dormitory: ____________________

(2) Family: ____________________

(3) Transient: ____________________

h. Food service.

(1) Types (dining halls, cafeterias, fast food, etc.): ____________________

(2) Capacities: ____________________

(3) Operating hours (24 hrs for shift workers): ____________________

____

i. Administration:

____

j. Personnel services:

k. Medical and dental :

(1) Hospital (no. of beds, types of clinics, dependent care):

(2) Clinic (no. of beds, types of services, dependent care):

5. Off-site support.

a. Power sources (capacity/reliability):

b. Other utilities.

(1) Water supply (quality and quantity):

(2) Sewage disposal:

(3) Natural gas:

c. Maintenance and services.

(1) Communications repair and parts:

(2) Data processing repair and parts:

(3) Other types of repair and parts:

d. Communications.

(1) voice (access to networks): ______________________________

____

(2) Data (access to networks): ______________________________

____

e. Labor sources.

(1) Construction: ______________________________

(2) Other skilled: ______________________________

(3) Manual : ______________________________

f. Transportation.

(1) Access roads (condition capacity): ______________________________

____

(2) Air (proximity of airport): ______________________________

____

(3) Ground (road and rail): ______________________________

____

(4) Sea (proximity of port facility): ______________________________

____

g. Energy and fuel sources.

(1) Coal: ______________________________

(2) Oil: ______________________________

(3) Natural gas; ______________________________

(4) Geothermal: ______________________________

(5) Solar: ______________________________

h. Housing.

(1) Houses: ____________________

(2) Apartments: ____________________

i. Food service.

(1) Restaurants (type and hours of operation): ____________________

____

(2) Fast foods (type and hours of operation): ____________________

____

j. Recreational facilities:

____

____

k. Local standards, laws, and customs (as they influence the operation of a DoD facility).

(1) Construction practices and standards: ____________________

____

(2) Social customs: ____________________

____

(3) Geopolitical considerations: ____________________

____

(4) Other considerations: ____________________

____

40. Power system checklist.

1. Name, address, and telephone number of power supplier: ____________________

____

2. Location of power generating plant: ____________________________________

____

3. Location of nearest substation: ____

____

4. Available power; Voltage: ____________________ Frequency: __________________

5. Method of power distribution: Overhead Underground

6. Is available power adequate? Yes No

7. Will a dedicated transformer(s) be required? Yes No

8. Will transient voltage protection be incorporated into the power company switch gear at the facility entrance? Yes No

9. If transient suppressors are to be installed, will they be between the power transformer and switch gear? Yes No

10. Is backup power required? Yes No

11. If backup power is required, what types of systems will be used?

____

____

12. Will frequency conversion be required to power fixed or mobile DoD equipment? Yes No

13. Have tests been conducted to determine soil resistivity and conductivity? Yes No

14. What facility grounding method will be used? ____________________________

____

15. Will air terminals (lightning rods) be used for lightning protection? Yes No

16.. Will dedicated power panels and isolated ground outlets be used for sensitive electronic equipment? Yes No

17. Will facility transient suppressors be installed? Yes No

18. What type of suppression devices will be used?

19. Where will the suppression devices be installed?

20. Will facility powerline filters be required? Yes No

21. Are transient protectors built into equipment which will be operated in the facility? Yes No

22. Will equipment be used in the facility that may generate transients which could affect other equipment? Yes No

23. Will isolation transformers be used in areas where sensitive electronic equipment is installed? Yes No

24. Are other power subscribers nearby which may generate powerline transients? Yes No

25. What is planned to reduce or eliminate the effect of these transients?

26. Is the facility in an area of high lightning activity? Yes No

27. What is the frequency of electrical storms in the area?

28. Will equipment be installed which requires dc voltage? Yes No

29. What dc voltages are required?

30. What method will be used to supply dc voltages?

a. Rectifier/chargers and batteries
b. Rectifiers
c. Dc generators
d. Converters

31. Will dc-to-dc converters be used? Yes No

32. Will emergency backup power be required? Yes No

33. What type of emergency conversion will be used?

a. Static UPS
b. Rotary UPS Battery
c. Alternative power source

34. If a battery room is used, have adequate safety measures been considered? Yes No

35. Will only mission essential equipment be used while power is being supplied by backup systems? Yes No

36. How long must operation be sustained when power is being supplied by backup systems?______________________________________

37. Will the backup power system provide for sustained operations as required? Yes No

50. <u>Energy conservation checklist for environmental control</u>.

1. General information.

a. Do site survey data include complete information on local weather conditions?________

b. Do site survey data include useful information concerning site features which can affect energy consumption?________

c. Have the appropriate design conditions been used to determine the types and sizes of environmental control equipment?________

d. Will environmentally sensitive electronic areas, such as computer rooms, be provided with dedicated and backup HVAC systems?________

e. Has an energy management program been established for the facility?________

2. Heating system.

a. Have all heating requirements been included in heating load calculations?________

b. Has use of an economical and available fuel source been considered in the selection of heating equipment?________

c. Have fuel efficiency, heat recovery applications, and other energy-saving techniques been considered in the design of the heating system?

d. Will forced-air ductwork or hot water piping be properly insulated?

e. Will forced-air ductwork and hot water piping be provided with the necessary dampers and valves, respectively, to balance and control flow rates?

f. Has a reasonable growth potential been incorporated into the heating system design?

3. Cooling system.

a. have all cooling requirements been included in cooling load calculations?

b. Where acceptable, has energy-efficient cooling equipment been selected?

c. Has the cooling equipment been matched to the characteristics of the total cooling load (sensible cooling versus latent cooling)?

d. Have energy-efficient techniques such as economizer cycles, off-peak operating cycles, and VAV systems been considered in the design?________________

e. Has a reasonable growth potential been incorporated into the cooling system design?________________

4. Solar energy.

a. Does the architectural design of the facility consider the control and application of solar radiation?________________

b. Will solar energy be applied for building heating and cooling?________________

c. Has daylighting been considered in building design?________________

d. Will solar energy be used to produce hot water?________________

5, Construction.

a. Will the construction materials and techniques used produce a tight building, which minimizes unwanted heat gains and losses?________________

b. Will the building be properly insulated, to reduce heating and cooling loads?____

____

c. If building is hardened, will the potential environmental control advantages be exploited?______________________________

____

d. Will sensitive electronic areas, such as computer rooms, be configured and operated so that the indoor environmental conditions can be maintained without excessive operation of HVAC equipment?____________________

____

____

DESIGN CONCEPT FOR AN EFFICIENT SMALL FACILITY

10. Scope. This appendix shows an earth-sheltered design concept that could be applied to small DoD electronics facilities in all but artic locations. It is a facility that can be operated unattended or attended. Although glass

relatively invulnerable to functional damage by weather, vandalism, or terrorism.

20. Applicable documents. This section is not applicable to this appendix.

30. Definitions. See section 3.1 of handbook.

40. Design features.

40.1 Site selection. An earth-sheltered building, such as depicted in figure E-1, can be built on any terrain. Although preferred, it is not necessary to use a south-sloping (Northern hemisphere) hill for an earth-sheltered building. It can be constructed on level ground and the physical and economic benefits obtained by earth berming. With either type of site, a swale is required behind the structure to obtain necessary drainage. Core samples should be taken at any prospective site to determine exact soil conditions.

40.2 Advantages. The advantages of an earth-sheltered building are:

Physical security - weather, fires, and vandals are not likely to damage a building of poured concrete with earth cover on three sides and the top. The lower profile and basic construction methods afford some blast resistance. Nuclear radiation effects can easily be reduced by a factor of 50 to 1000.

b. Less problems with EMI and noise - the effects of EMI from external sources is reduced by the surrounding earth; a facility ring ground can be easily located at a depth where the soil will remain moist and highly conductive. Audible noise control at facilities near runways or highways is vastly improved with earth-sheltered construction.

c. Lower cost heating and cooling - several feet of earth cover make it possible to heat and cool the facility for a small fraction of the cost for an above-ground structure. Exterior maintenance costs are greatly reduced as well as the chance of structural damage due to wind.

40.3 Theory of operation - winter. The addition of a Trombe wall a few inches behind the south-facing windows vastly improves security and offers a method to furnish most of the required heating. Trombe walls are usually 6 or more inches thick and made of poured concrete. Small slots (vents) with specific dimensions are used to control the heating cycle as shown in figures E-Za and b. As expected, if the glazing is damaged from any cause,

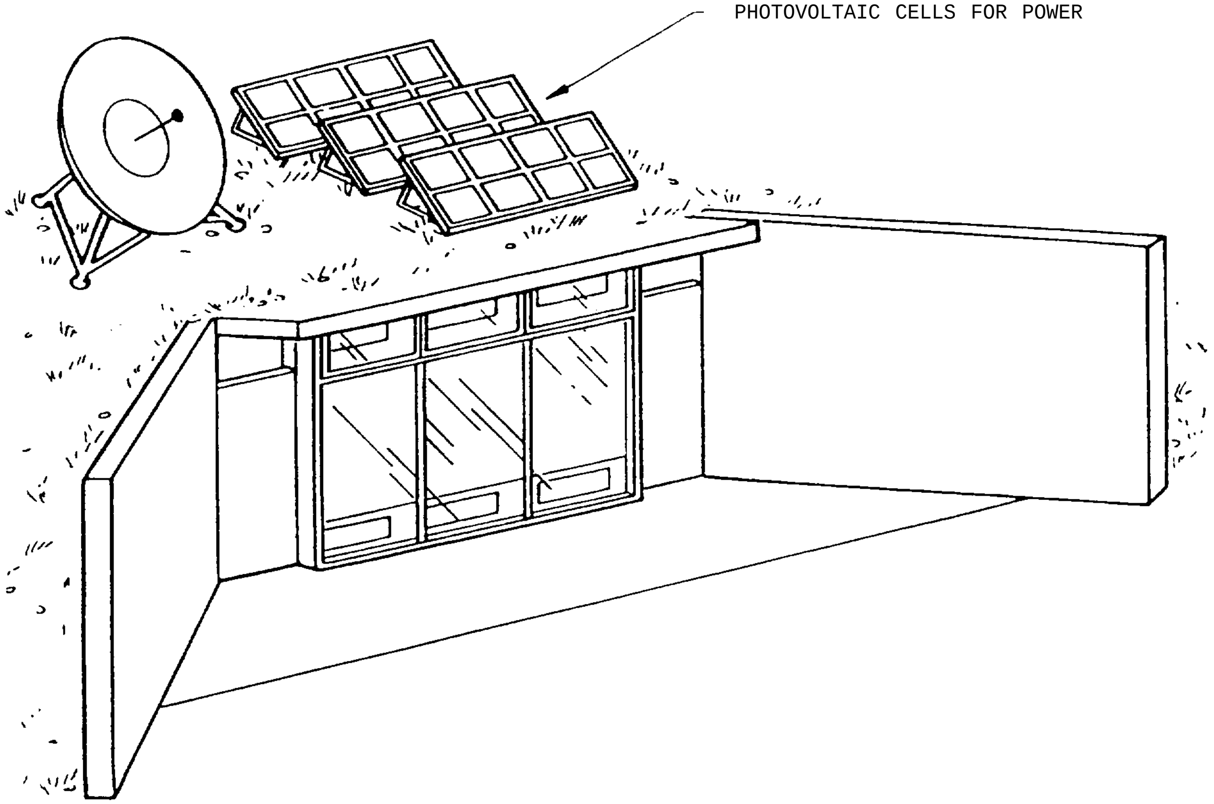
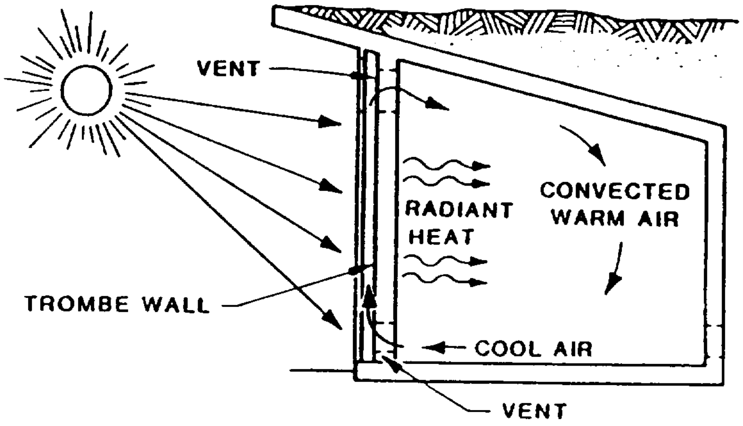
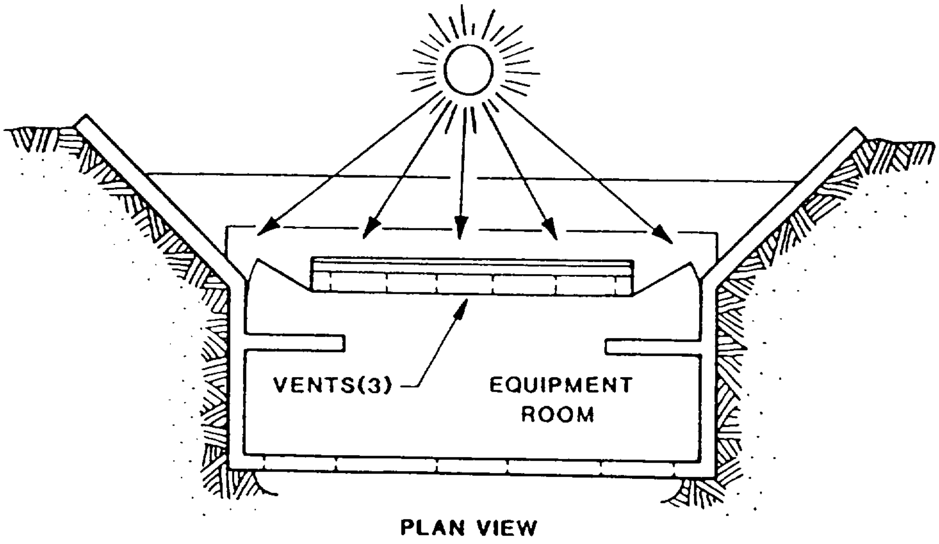


FIGURE E-1. Earth-sheltered building.



A.



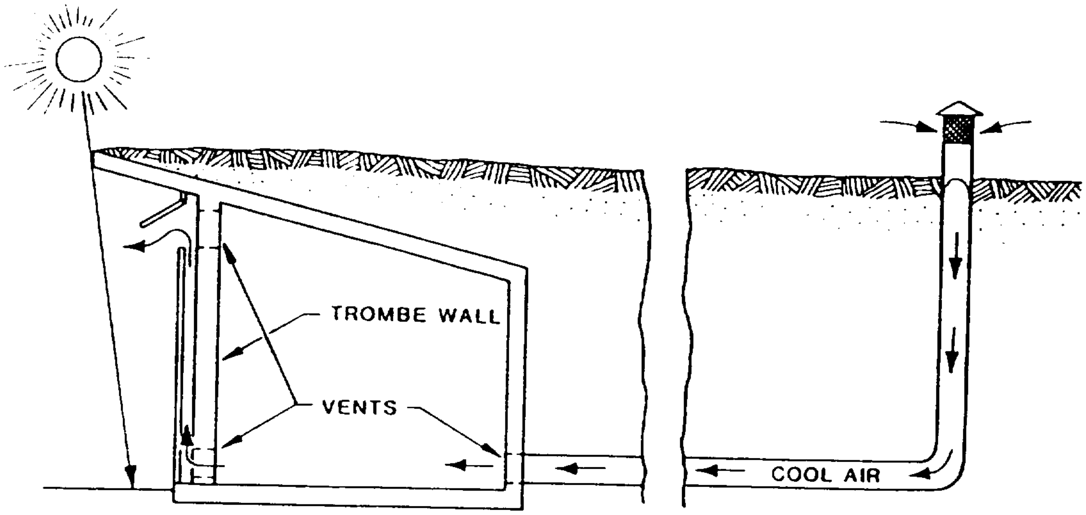
B.

FIGURE E-2. Winter operation.

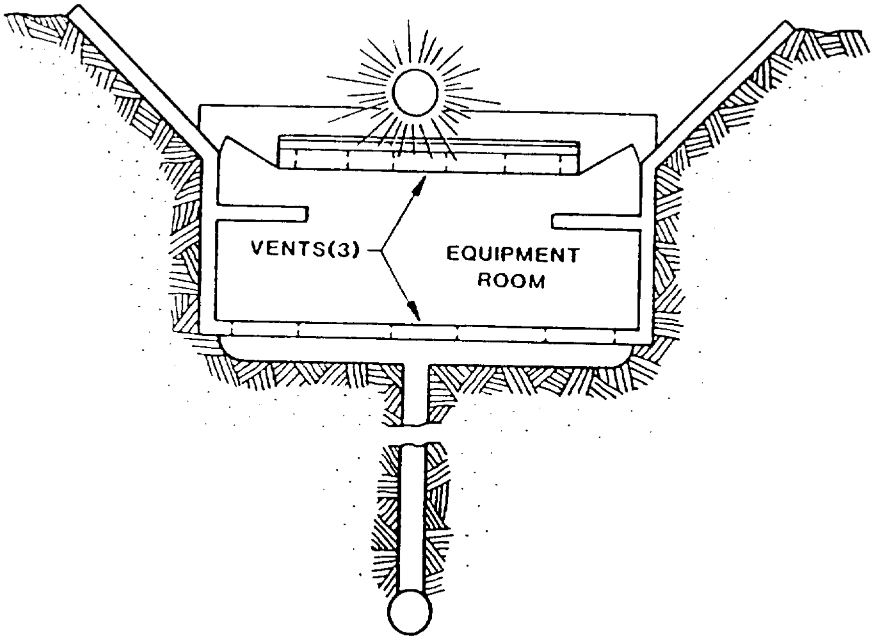
some of the natural heating will be temporarily disrupted, but access to the building by unauthorized personnel continues to be denied. The small slots in the Trombe wall can also be covered with expanded metal to prevent access to the interior by tossed objects. Heating with a Trombe wall is classed as indirect gain, where solar energy is absorbed on the outer surface of a masonry wall, but transfer through the wall is delayed. Properly designed, the outer surface of a glazed concrete wall gets very hot during the day and the heat penetrates the wall and warms the inside of the structure after sunset. This arrangement also pulls cooler air from the floor (figure E-2a and b) through the lower vents and across the hot surface between the glass and concrete. This rising column of air is heated by thermosiphon action and returned to the room. At night, the lower vents automatically close to prevent loss of building heat.

40.4 Theory of operation - summer. In summer, the Trombe wall is used to provide cooling (figure E-3, a and b). The structure roof overhang is carefully sized (based on latitude) to reduce the amount of solar radiation impacting the outer surface of the wall during the summer months. The upper Trombe wall vents are opened to the outside, and rear floor level vents are opened to accept air from a cool tube. Cool tubes have typical dimensions of 8 inches (20 cm) in diameter and 100 feet (30 m) in length, and are buried at the constant-temperature level of the particular geographic location. The warm, front surface of the Trombe wall pulls the cool air from the floor and exhausts it between the glass and the wall, and outside through the open top vents. The usual application of media filters will be required to control dust and other particulate. in high humidity areas, it may be necessary to provide a dry sump at the bottom of the vertical portion of the cool tube.

40.5 Limitations on using natural heating and cooling. As expected, equipment that requires precise control of humidity and temperature is not a good-candidate for installation in an earth-sheltered structure that uses only natural heating and cooling. But if conventional heating and cooling systems are used, all other advantages of earth-sheltering apply.



A.



B. PLAN VIEW

FIGURE E-3. Summer operation.

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3. Heating, Piping, Air Conditioning, "Variable Air Volume B.VAV) System Comparison," November 1986, page 186.

4. Heating, Piping, Air Conditioning, "Dedicated Module (DM) Types," September 1986, page 112.

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8. Heating, Piping, Air Conditioning, "Redundant Fiber-optic Loop Transmission System, March 1986, page 111.

9. Consulting-Specifying Engineer, "Characteristics of Battery Types," October 1976, page 99.

10. IEEE Std 587-1980, Guide for Surge Voltages in Low-Voltage Power Circuits, January 1980.

11. AFR 88-15, Criteria and Standards for Air Force Construction.

12. DCA Instruction 350-175-1, Design Practices for High Attitude Electromagnetic Pulse (HEMP) Protection (scheduled to be replaced by MIL-STD-188-125 and MIL-HDBK-423).

*U.S. GOVERNMENT PRINTING OFFICE: 1990--504-034/50045

NOT MEASUREMENT
SENSITIVE

MIL-HDBK-411B
15 MAY 1990

SUPERSEDING
MIL-HDBK-411A
21 MAY 1971

MILITARY HANDBOOK

POWER AND THE ENVIRONMENT

FOR

SENSITIVE DoD ELECTRONIC EQUIPMENT

(ENVIRONMENTAL CONTROL)

VOLUME III

ASMC N/A

AREA SLHC

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1. SCOPE.

1.1 Purpose. Volume III of this three-volume handbook is a reference for the planning and engineering of environmental control systems for fixed Department of Defense (DoD) communications, data processing, and information systems facilities. The engineering concepts contained herein should be selectively applied to the environmental control elements of DoD fixed facilities. DoD communications and data processing installations include equipment rooms and spaces needing more precisely controlled environments than comfort spaces. The more limiting parameters within these rooms and spaces are established specifically for the equipment being used. Outside these specially designed areas, where personal computers (PCs) and other electronic office equipment are used, the environment is the responsibility of the user. Volume II should be used to ensure that power protection or conditioning for this equipment follows guidance provided therein. Volume I addresses these subjects in general terms for the planner, manager, *or* executive. Volume 11 addresses power system engineering considerations. Volume III addresses environmental control system engineering considerations.

1.2 Applicability. Volume III applies to and discusses the following topics:

a. Matching types of building construction and environmental control systems to the local geographical, terrain, and weather features.

b. Characteristics and operation of environmental control system equipment.

c. Special types of construction and materials used to support and protect communications and data processing rooms and spaces.

d. Indoor atmospheric conditions required for communications and data processing equipment.

e. Identification of the types of environmental control systems and equipment best suited for use in communications and data processing facilities.

f. Methods of monitoring, controlling, and recording of environmental control system performance.

g. Energy conservation considerations.

h. Protection of the environment.

1.3 Application guidance. This handbook is intended to assist in selecting and planning environmental control systems to be installed or upgraded at DoD communications-electronics facilities and computer-based facilities. It is applicable to the engineering effort during initial establishment of a facility, or during upgrade of an existing facility. This handbook introduces practices and procedures that should be considered during the engineering design. The guidance is not to be interpreted as directing that any or all of these control systems be employed at any given facility. Further, it is not to be used solely as a justification for retrofit of existing DoD communications, data processing, and information systems facilities.

1.4 Safety.

1.4.1 Safe work place. Occupational Safety and Health Administration (OSHA) regulations require a safe work place at all times. Although OSHA does not approve specific tools or products, there are Federal specifications for safety tools and they are listed in the appropriate Qualified Products Lists (QPLs).

OSHA regulations state that employees shall not be required to work in surroundings or under working conditions which are unsanitary, hazardous, or dangerous to their health and safety. Employers are required to initiate and maintain programs which comply with this requirement. These programs include inspections of job sites, materials, and equipment. They also ascertain that use and operation of equipment or machinery is by qualified employees.

1.4.2 Confined spaces. The National Institute of Occupational Safety and Health (NIOSH) estimates that millions of workers may be exposed to hazards in confined spaces each year. Investigation of confined space injuries and fatalities indicates that workers generally do not recognize they are working in a confined space with unforeseen hazards. These studies show that testing and monitoring of the atmosphere are often not performed, and that rescue procedures are seldom planned.

NIOSh'S definition of a confined space is "a space which by design has limited openings for entry and exit; unfavorable natural ventilation which could contain or produce dangerous air contaminants, and which is not intended for continuous employee occupancy."

1.4.3 Electrical/electronic equipment. Safety procedures should be established for electronic equipment employing high voltages or radiating high-energy fields. Safety requirements have been established in individual military department documents that should be reviewed prior to designing systems in accordance with guidance contained herein.

Remember these four rules:

a. Ground everything that might accidentally become energized.

b. Keep electricity separated from materials that are not to be electrified.

c. Keep heat and sparks (from electrical conductors and equipment) from starting a fire or triggering an explosion.

d. Do not assume safety: electrical equipment is dangerous until made or proven safe.

2. APPLICABLE DOCUMENTS

2.1 Government documents.

2.1.1 Standards, and handbooks. The following standards and handbooks form a part of this document to the extent specified herein. Unless otherwise specified, the issue of these documents are those listed in the issue of the Department of Defense Index of Specifications and Standards (DoDISS) and supplement thereto, cited in the solicitation.

STANDARDS

FEDERAL

FED-STD-1037	Glossary of Telecommunication Terms

MILITARY

MIL-STD-882	Standard Safety Program Requirements
MIL-STD-1472	Human Engineering Design Criteria for Military Systems, Equipment and Facilities

HANDBOOKS

MIL-HDBK-232	RED/BLACK Engineering-Installation Guidelines
MIL-HDBK-419	Grounding, Bonding, and Shielding for Electronic Equipments and Facilities
MIL-HDBK-420	Site Survey Handbook for Communications Facilities
MIL-HDBk-1001/2	Materials and Building Components

(Unless otherwise indicated, copies of Federal and military specifications, standards, and handbooks are available from the Standardization Documents Order Desk, Bldg 4D, 700 Robbins Avenue, Philadelphia, PA 1911 -5094.)

MILITARY MANUALS

(Navy) NAVFAC DM-1.03	Architectural Acoustics, Functional Requirements, Design, and Technology
(Navy) NAVFAC DM-3.16	Thermal Storage Systems
(Navy) NAVFAC DM-3.3	Heating, Ventilating, Air Conditioning Systems and Dehumidifying Systems

(Navy) NAVFAC DM-3.6	Central Heating Plants
(Navy) NAVFAC DM-5.7	Water Supply Systems
(Navy) NAVFAC DM-12.1	Electronic Facilities Engineering

NOTE: Selected NAVFAC DMs are being redesignated as military handbooks. The DODISS should be reviewed for current titles.

(Unless otherwise indicated, Navy publications are available from the Standardization Documents Order Desk, Bldg 4D, 700 Robbins Avenue, Philadelphia, PA 1911-5094.)

(Army) TM 5-785 (Navy) NAVFAC P-89 (Air Force) AFM 88-29	Engineering Weather Data
(Army) TM 5-805-4 (Navy) NAVFAC DM-3.10 (Air Force) AFM 88-37	Noise and Vibration Control For Mechanical Equipment
(Army) TM 5-815-2 (Air Force) AFM 88-36	Energy Monitoring and Control Systems (EMCS)

(Unless otherwise indicated, military department publications are available through the specific department publications distribution center.)

2.1.2 Other Government publications. The following other Government publications form a part of this handbook to the extent specified herein. Unless otherwise specified, the issues are those cited in the solicitation.

(As a result of the cancellation of DoD 4630.7-M, Construction Criteria Manual, no DoD-level document on construction criteria is currently available. Individual military departments are developing construction criterial documents. Appropriate publications distribution centers should be contacted to determine availability of applicable documentation.)

2.2 Non-Government publications. The following document(s) form a part of this document to the extent specified herein. Unless otherwise specified, the issues of the documents which are DoD adopted are those listed in the issue of the DoDISS specified in the solicitation. Unless otherwise specified, the issues of documents not listed in the DoDISS are the issues of the documents cited in the solication.

AMERICAN SOCIETY OF HEATING, REFRIGERATING, AND AIR CONDITIONING ENGINEERS (ASHRAE)

ASHRAE Handbook	Fundamentals
ASHRAE Handbook	Equipment

ASHRAE Handbook	HVAC Systems and Applications
ASHRAE GRP 158	Cooling and Heating Load Calculation Manual

(Applications for copies should be addressed to the American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc., 1791 Tullie Circle NE, Atlanta, GA 30329.)

ILLUMINATING ENGINEERING SOCIETY OF NORTH AMERICA (IES)

IES HDBK	IES Lighting Ready Reference Handbook

(Applications for copies should be addressed to the Illuminating Engineering Society of North America, 345 East 47th St. New York, NY 10017.)

2.3 order of precedence. In the event of a conflict between the text of this handbook and the references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained. In the event of a conflict between this handbook and another military handbook, the more specific handbook shall normally take precedence. For example, at a satellite earth station, the military handbook on that subject (MIL-HDBK-412) would take precedence. Similarly, a conflict concerning grounding, bonding, and shielding procedures would be resolved in favor of the handbook that deals specifically with that subject; in this case, MIL-HDBK-419.

3. DEFINITIONS

3.1 Terms and definitions. For definitions of the terms used in this handbook, refer to Federal Standard 1037 (Glossary of Telecommunication Terms), except as listed below, which are uniquely defined for the purpose of this handbook.

absorptance	The ratio of the amount of radiant energy absorbed by a surface to that amount falling on the surface.
absorption	The process of extracting one or more substances from a fluid (air or liquid) by the holding action of a special material called an absorbent.
adsorption	The process of extracting one or more substances from a fluid by the adherence of those substances to the surface of a special material called an adsorbent.
air cleanliness	The amount of filterable particulate material in the atmospheric air.
air quality	The chemical composition of the atmospheric air.
anemometer	An instrument that measures air speed at a given point.
arrester	A protective device used as a bypass to ground for transients resulting from such things as lightning or EMP that are coupled to an antenna or other conductor. An arrester is capable of reducing the voltage and current of a transient applied to it and restoring itself to the original condition.
balance	Regulating the flow of air or liquid in distribution networks (ducts or piping).
British thermal unit (Btu)	The amount of heat that must be added to or subtracted from one pound of water at 60 °F to produce a temperature increase or decrease of 1 °F.
building envelope	The outer shell or elements (ceiling, floor, and walls) of a building that enclose environmentally controlled spaces.

candela (cd)	The basic unit of luminous intensity derived from a blackbody radiator operating at a prescribed pressure and temperature.
clean room	A space in which temperature, humidity, air cleanliness, air quality, air movement, air pressure, noise, and vibration are very precisely controlled. The activities permitted within a clean room are also controlled. Clean rooms are often classified according to the maximum concentration of particulate allowed per unit volume of air. Special grounding systems and other transient protection may also be provided, especially in an electronic clean room.
coefficient of utilization (CU)	In illumination engineering, the fractional portion of the initial lamp lumens (direct or reflected) that reaches the work surface.
cogeneration	The simultaneous generation and use of electrical power and heat energy from a single fuel source.
coil	A cooling or heating element made of tubing or piping. Typically formed in a helical shape, either with or without fins.
compressor	A device that increases the pressure of gas by mechanical means.
condensate	Liquid produced by the condensation of a vapor.
condensation	The process of changing a vapor to a liquid by extracting heat from the vapor.
condenser	A device, usually made up of pipes or tubing, that liquifies a vapor when heat is extracted.
conditioned air	Indoor atmospheric air whose temperature, humidity air cleanliness, and air quality are regulated.
conditioned space	A room or space that is provided with conditioned air.

conductance	The amount of heat a standard section of nonhomogeneous material will transmit under given temperature conditions.
conduction	A mode of heat transfer which occurs when bodies or materials with different temperatures come in contact.
conductivity	The amount of heat a unit section of homogeneous material will transmit under given temperature conditions.
controller	A device that monitors a parameter and initiates a signal to a controlled device to initiate some corrective action when deviations from a set point are observed.
controlled device	A device that starts some corrective action when a signal from a controller is received.
convection	A mode of heat transfer in which a fluid (air or liquid) is used to transport heat. The fluid is first heated by conduction. Its higher temperature causes it to expand and move, because of lighter density. The motion creates currents which move the heated fluid to areas of lower temperature.
cooling coil	A coil which cools surrounding fluid (air or liquid) by heat exchanger action. The coil acts as either an evaporator for refrigerant or a channel for chilled water circulation.
cooling load	The maximum amount of heat that a cooling system will be required to remove.
cooling tower	A structure in which water is circulated and cooled by conduction and evaporation into the air.
coulomb	The metric unit of electrical charge equal to the amount of electricity transferred by a current of one ampere in one second.
damper	A device to control the flow of air at an inlet, outlet, or inside ductwork.

daylighting	The application of natural luminance in the form of top lighting, sidelighting, or combinations thereof, to provide a portion of all of the light in a structure.
degree day	The number of degrees of variation of the mean outdoor temperature from a base temperature of 65 °F (18.3°C), over 24 hours.
design conditions	The high and low temperature values and related conditions, specified as limits, used to calculate heating and cooling loads. For the DoD, they are listed in the triservice manual: Engineering Weather Data (AFM 88-29, NAVFAC P-89, and TM 5-785).
direct digital control	The automated monitoring and control of the indoor environment of a building or space, using computer-based devices.
dry-bulb temperature	The temperature of the air measured by an ordinary thermometer.
dry-type transformer	A transformer which is cooled by the natural or forced circulation of air, as opposed to a liquid.
ductwork	A system or network of ducts used for the distribution or exhaust of air. Ducts are also used for distributing power and signal cabling.
economizer	An HVAC operating cycle in which cool outside air is used for cooling and the load placed on mechanical cooling is reduced.
efficacy	See luminous efficacy.
enthalpy	The sum of sensible and latent heat in a substance. Usually concerned with moist air. Also called total heat.
environmental control	The conditioning of indoor atmospheric environment, including the monitoring and control of temperature, humidity, air quality, air cleanliness, and air circulation.

evaporation	The process in which a liquid changes to a vapor (gas).
evaporator	The heat exchanger, used commonly in refrigeration systems, in which the refrigerant absorbs heat during evaporation.
exitance	See luminous exitance.
fault current	The current which flows in a circuit as a result of specified abnormal conditions.
fenestration	Any area of an outside wall of a building, such as a window, that allows light to pass.
grounded conductor	A conductor in a power distribution system (usually designated the neutral) which is intentionally earth grounded either solidly or through a grounding device. The outer jacket of the conductor, if insulated, is white in color.
grounding conductor	A conductor which carries no current under normal conditions. It serves to connect exposed metal surfaces to an earth ground to prevent hazards in case of breakdown between current-carrying arts of a power distribution system and the exposed surfaces. The outer jacket of the conductor, if insulated, is green in color, with or without a yellow stripe.
head	A unit of fluid pressure, usually expressed in feet. In typical usage, a given pressure is defined by the height of a column of water it will support.
heat	Energy in a substance associated with the random motion of its atoms or molecules or from radiation striking the substance. The temperature of the substance is a measure of this energy (see also latent heat, radiant heat, and sensible heat).
heat exchanger	A device that transfers heat between two physically separated fluids.

heat gain	The heat which enters a building or space through the ceiling, floor, and walls, or is generated by personnel or equipment in the building or space.
heat loss	The heat loss through the ceiling, walls, and floor of a building or space.
heat pump	A device which uses a thermodynamic cycle to supply heat to or remove heat from a controlled space.
heat transfer	The movement of heat by conduction, convection, or radiation.
heating load	The highest demand for heat that the heating system of a building will be required to supply.
humidistat	A device which monitors and controls indoor humidity.
humidity	The amount of water vapor present in atmospheric air.
humidity ratio	Weight or mass ratio of water vapor to dry air in the atmospheric air/water vapor mixture.
intrinsically safe	The incapability of devices to release sufficient energy to cause ignition of a specific atmospheric mixture under normal or specified abnormal conditions.
joule	The energy required to transport one coulomb between two points having a potential difference of one volt.
latent heat	Heat resulting from a change of state (solid, liquid, or gas) of a substance.
load shedding	The capability of an electrical distribution system to remove noncritical loads during power shortages.
lumen	The unit of luminous flux. The luminous flux emitted within a unit solid angle by a point source having a uniform intensity of one candela.

luminaire	A complete lighting unit consisting of a lamp or lamps with arts to distribute the light, connect the lamps to a power source, and protect the lamps from damage.
luminous efficacy	The quotient of the total luminous flux emitted by the total lamp power input. It is expressed in lumens per watt.
luminous exitance	The density of luminous flux leaving a surface at a point.
nanojoule	One-billionth of a joule.
one-line power diagram	A diagram which, by means of single lines and graphic symbols, shows the layout of an electrical circuit and the components used therein.
phon	A subjective unit which has a nonlinear scale and is used to quantify the loudness of sounds using a 1000-hertz tone as reference.
power factor (PF)	The ratio of active power and apparent power.
protective relay	A relay (mechanical or solid-state) used to detect abnormalities in a power system or component and initiate appropriate warning or control action.
psychometrics	The area of physics that deals with the determination of the thermodynamic properties of moist air and the application of that knowledge for analysis and problem solving.
radiant heat	Heat transmitted by radiation, rather than by conduction or convection.
radiation	The conveyance of heat by electromagnetic waves in the infared spectrum (between the EHF and visible light bands).
refrigerant	Heat transfer fluid used in refrigeration systems.

relative humidity	The amount of water, in vapor form, with respect to that at saturation of atmospheric air, at given dry-bulb temperature and barometric pressure, expressed as a percentage.
sensible heat	The heat energy associated with the motion of atoms and molecules in substance.
set point	The desired level or value of an environmental parameter at which a control is set.
sone	A subjective unit which has a non-linear scale and is used to compare the levels of sounds. One sone represents the loudness of a 1000-hertz tone at 40 dB.
suppressor	A device or circuit used to reduce or eliminate unwanted signals, noise, or interference. Suppression methods include shielding, filtering, grounding, relocation, or redesign.
supply air	Air that is supplied to a room or space through a duct system.
switching transients	An over-voltage in an electric circuit caused by a switching action in the power grid or in user equipment.
thermostat	A device which monitors and controls indoor temperature.
transient	A momentary surge on a commnication or power line that may produce false signals or triggering and can cause insulation or component upset or failure.
transient voltage	Generally used to describe a momentary surge in an electrical circuit that exhibits a fast-rising current and voltage waveform.
Trombe wall	A concrete, stone, or masonry south-facing heat storage wall, up to 16-inches thick, named for one of its developers, Dr. Felix Trombe.

variable air volume (VAV)	A forced-air environmental control system which varies the amount of conditioned supply air to controlled rooms and spaces at constant temperature to maintain design conditions, as opposed to constant volume air at varying temperature.
voltage sag	Generally used to describe a momentary voltage reduction in a power distribution system of 10-35 percent below nominal level.
voltage surge	Generally used to describe a momentary voltage increase in a power distribution system of 10-35 percent above nominal level.
wet-bulb temperature	The temperature registered by a thermometer with its bulb enclosed in a sock, wetted by water, and exposed to a stream of air.

3.2 Acronyms and abbreviations. The following acronyms and abbreviations used in this handbook are defined as follows:

ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning engineers
BH	Btu per hour
BIL	Basic insulation level
Btu	British thermal unit(s)
C	Conductance
CCTV	Closed-circuit television
cd	Candela
cfm	Cubic feet per minute
CLF	Cooling load factor
CLTD	Cooling load temperature difference
COP	Coefficient of performance
CU	Coefficient of utilization
DBT	Dry-bulb temperature
DDC	Direct digital control
DM	Dedicated module
DPT	Dew point temperature
E	Illuminance
EPA	Environmental Protection Agency
ESD	Electrostatic discharge
ETS	Environmental tobacco smoke
fc	Foot candle
FIPS	Federal Information Processing Standards
GBS	Grounding, bonding, and shielding
GFCI	Ground fault circuit interrupter
h	Enthalpy
HID	High-intensity discharge
HVAC	Heating, ventilating, and air conditioning
IQA	Indoor air quality
IC	Interrupting Capacity
IEEE	Institute of Electrical and Electronics Engineers
IES	Illumination Engineering Society of North America
k	Conductivity
kPa	kilo Pascals
L	Luminance
lm	Lumen
LPG	Liquified petroleum gas
L/s	Liters per second
M	Luminous exitance
MCC	Motor control center
MCWBT	Mean coincident wet-bulb temperature
NC	Noise criteria
NEC	National Electrical Code
NEMA	National Electrical Manufacturers Association
NFPA	National Fire Protection Association
NIOSH	National Institute of Occupational Safety and Health

NOAA - National Oceanic and Atmospheric Administration
0 - Luminous flux
OA - Outside air
OSHA - Occupational Safety and Health Administration
Pa - Pascals
PF - Power factor
psi - Pounds per square inch
psig - Pounds per square inch gauge
q - Cooling or heating load component
Q - Quantity of light
R - Resistance (heat transfer)
RC - Room criteria
SEER - Seasonal energy efficient ratio
SI - International System of Units
TCE - Trichloroethylene
THD - Total harmonic distortion
TNF - Trintorflourenone
U - U-factor or heat loss coefficient
UL - Underwriters Laboratories
VAV - Variable air volume
VCP - Visual comfort probability
WBT - Wet-bulb temperature

4. GENERAL REQUIREMENTS

See Volume I of this handbook.

5. DETAILED REQUIREMENTS

5.1 General. The goal of designing the environmental control system of the physical plant to support an information system is fivefold:

a. Reliable, survivable, and economical operation of mission equipment.

b. Safety and comfort of personnel.

c. Minimize both initial and recurring costs.

d. Conservation of resources.

e. Protection of the environment.

While a standard floor plan may be applied to the mission equipment, the geographical location of the facility will dictate much of how environmental control is achieved. Accordingly, both the internal and external building construction parameters, materials, and environmental control techniques will vary with geographical location. The site survey must include complete information on the local climate, possible sources of utilities, construction practices, and laws and regulations concerning environmental protection. MIL-HDBK-420, Site Survey Handbook for Communications Facilities, provides the survey team with basic guidance on collecting these data. This information will be used to design the heating, ventilating, and air conditioning (HVAC), lighting, and humidity control systems, as well as methods to handle air, water, noise, and electronic pollution. All HVAC and related systems must function in an integrated manner to provide an optimum environment for communications and automatic data processing (ADP) equipment. This environment should meet the conditions recommended by the manufacturer and this handbook. It is of special importance to maintain conditions that minimize the potential for electrical transients, which can damage power-sensitive equipment and cause loss of data. The selection of major fuel sources can also be made from site survey data. The physical plant design must incorporate cost effectiveness and energy conservation through the selection of construction styles, power, and environmental systems appropriate to the geographical location. In foreign locations, the geopolitical situation should be assessed in terms of the stability of local governments and economies. Energy reuse techniques must be applied wherever possible. Both personnel and equipment must be afforded the physical protection deemed appropriate by the mission. Special considerations, such as storage of parts and supplies, and maintenance capabilities for sustained (button-up) operations, may be added to the design task. For example, below-grade construction might be utilized to exploit the physical security, electromagnetic shielding, and temperature stability it provides. Finally, the design must incorporate all mission requirements, environmental control, energy conservation, and environmental protection, in terms of available funds.

5.2 Fundamentals of environmental control. The purpose of this section is to develop an understanding of construction and HVAC industry definitions and terminology that are used throughout this handbook. For example, to the general public, the term “air-conditioning” refers to a cooling process applied to overcome the discomfort of hot weather. In modern usage in the construction and HVAC industries, air-conditioning is defined as the control of the indoor environment. This control includes dry-bulb temperature, humidity, air quality, air cleanliness, and air circulation. The terms “air-conditioning” and “environmental control” are considered to be synonymous within the DoD and the professional civilian community. The latter term will be used in this text to eliminate confusion and maintain consistency. The U.S. HVAC industry is still using English terms, such as British thermal units (Btu) and pounds per square inch (psi). Where appropriate, this handbook uses English terms with International System of Units (SI) equivalents.

5.2.1 Dry-bulb temperature (DBT). DBT is the everyday temperature that is measured in degrees Fahrenheit (°F) or Centigrade (C) to determine how hot or cold it is. The term is used to differentiate it from wet-bulb temperature measurement, which have special purposes in HVAC (see 5.2.6). Table I contains conversion formulas for Fahrenheit and Centigrade temperatures, as well as their relationships to the Kelvin and Rankine absolute temperature scales. The Kelvin scale uses centigrade units, while the Rankine scale uses Fahrenheit units. A commonly used temperature-based design parameter in HVAC is the “degree day”, which is defined as a heating or cooling unit that represents a one-degree variation from the base temperature of 65°F (see 5.3.1.3).

5.2.2 Humidity. Humidity refers to water vapor present in atmospheric air. Relative humidity is defined as the ratio of the partial pressure or density of the water vapor in air to the saturation pressure or density, respectively, at the same dry-bulb temperature and barometric pressure. Humidifying is the addition of water vapor to achieve a desired level of humidity. Dehumidifying is the removal of unwanted water vapor. The thermodynamic properties of the dry air and water vapor mixture (moist air) are very important in HVAC processes. Control of humidity is often accomplished in conjunction with other HVAC processes, including cooling and air cleaning. The maintenance of specific humidity ranges is essential to control electrostatic discharge, which can adversely affect power-sensitive equipment. The potential for electrostatic discharge and damaging dust increases when humidity levels become too low. Conversely, high humidity levels can cause swelling of cards and paper, which can cause data processing equipment to malfunction. More information on humidity can be found in 5.2.6.

5.2.3 Air quality. Air quality refers to the chemical composition of the air. This includes levels of carbon monoxide, carbon dioxide, radon gas, odors, toxic fumes, and oxygen.

TABLE I. Temperature conversion formulas.

Centigrade (°C) = 5/9 (°F-32)
Kelvin (K) = °C + 273.15
Fahrenheit (°F) = (9/5) °C + 32
Rankine (°R) = °F + 459.67

5.2.4 Air cleanliness. Air cleanliness refers to the amount of filterable particulate matter in the atmospheric air, such as dust. Air contaminants have a wide range of size and chemical composition. Solid particulate matter is loosely categorized as dusts, fumes, and smoke. Particulate size is measured in micrometers (μ m). One micrometer equals 3.937 x 10-5 inches. The air pollution known as smog often contains liquid particulate. Table II, from the 1985 ASHRAE Fundamentals Handbook, provides examples of air contaminants, and shows how the are sized and removed from the atmosphere. Controlling the accumulation of dust and other particle matter, in conjunction with maintaining design humidity ranges, is a large part of electrostatic discharge control. More information on air cleaning is presented in the discussions concerning indoor air quality (IAQ) and ventilation.

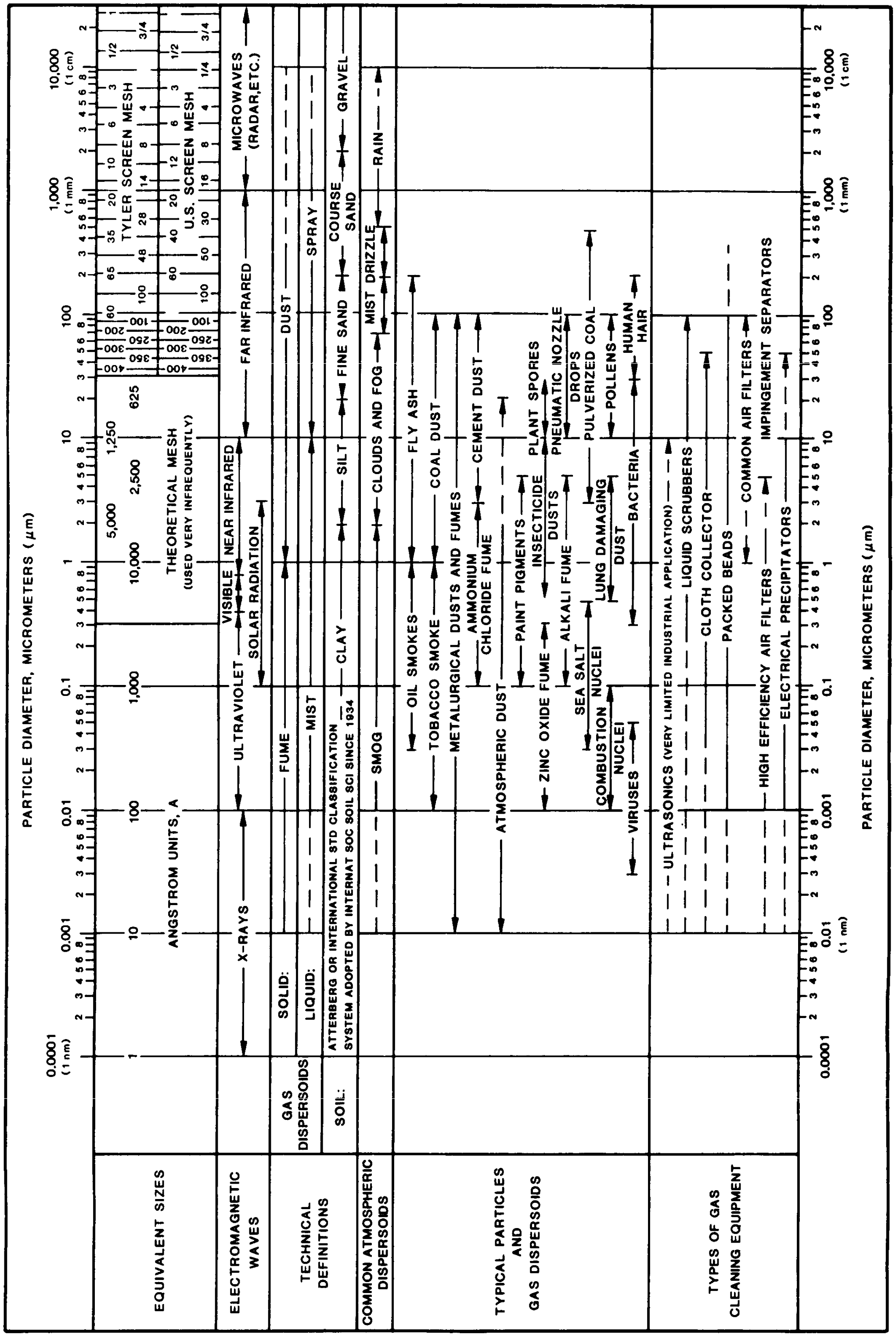
5.2.5 Air circulation. Air circulation refers to the movement of indoor air by natural or mechanical means, Other parameters of environmental control may be met concurrently with air circulation control. Air circulation should be accomplished with minimum disturbance or discomfort to personnel occupying the controlled air space. Detailed information on air circulation is presented later in the discussions of indoor air quality (IAQ) and ventilation.

5.2.6 Wet-bulb temperature and humidity. Wet-bulb temperature (WBT) refers to the temperature (°F or °C) measured by a thermometer with a wetted bulb that is exposed to a stream of air. The stream of air passing over the wetted bulb causes evaporative cooling and a temperature reading lower than that from a dry-bulb thermometer. As the amount of moisture in the air decreases, more cooling takes place, and a lower temperature is observed. It is common practice to measure both dry- and wet-bulb temperatures using a device called a sling psychrometer, which is illustrated in figure 1. The sling psychrometer is rotated manually around the swivel to create a rapid flow of air over the thermometers. Both dry- and wet-bulb temperatures can then be read simultaneously.

a. The wet-bulb temperature is very significant in HVAC. In conjunction with the dry-bulb temperature, it provides a means to determine the amount of water vapor (humidity) present in the air. It is closely related to the total heat (enthalpy) of the air. The dew point temperature (DPT) is the temperature at which the water vapor is saturated (100 percent relative humidity).

b. The humidity ratio, which is also called specific humidity, is the weight, or mass, ratio of water vapor to dry air in the atmospheric air and water vapor mixture. It may be expressed as pounds of water vapor per pound of dry air, or as grains (gr) of water vapor per pound of dry air. One pound equals 7000 grains. One grain equals 0.0648 grams.

TABLE II. Air contaminants.



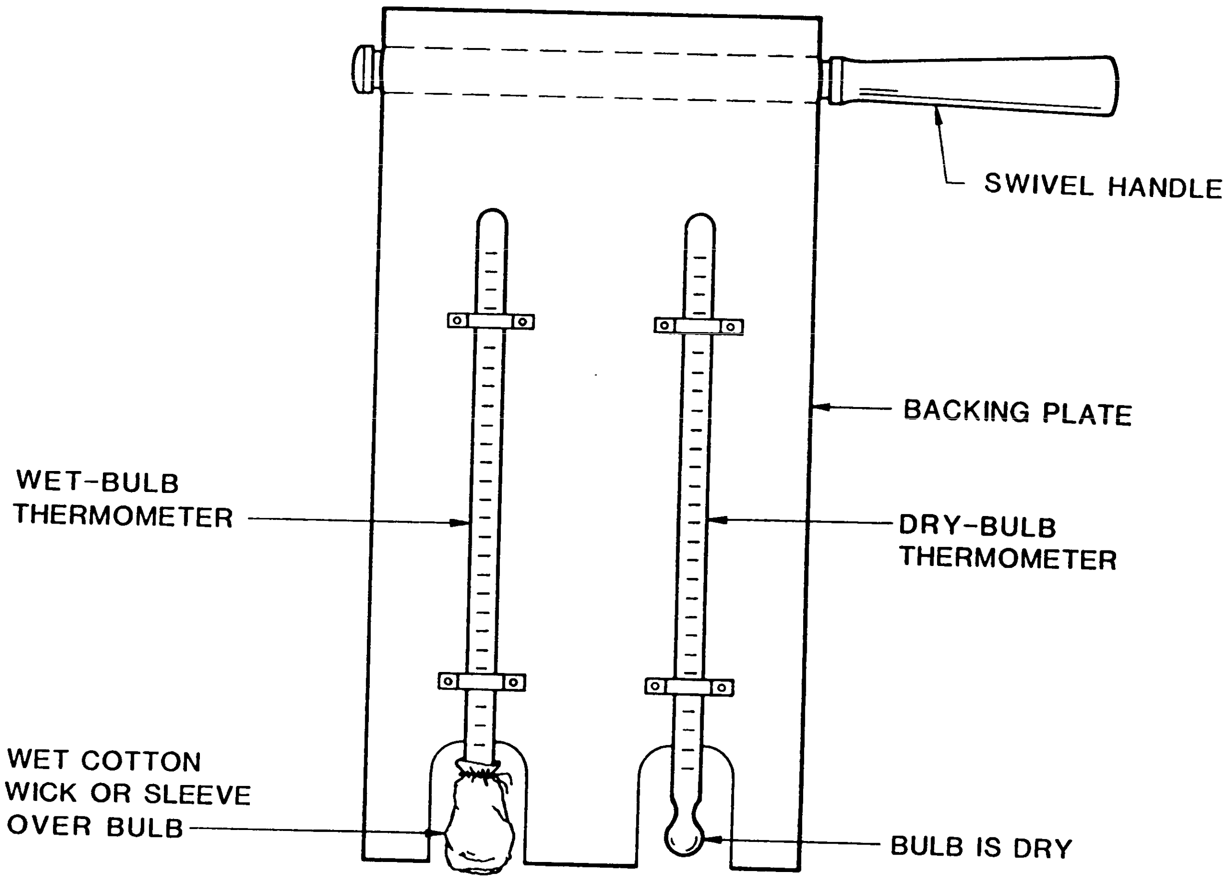


FIGURE 1. Sling psychrometer

c. Humidity is measured by sensing instruments called hygrometers. The sling psychrometer described above is a type of hygrometer. Related devices, called humidistats are used to control humidity. hey employ the physical changes that occur in organic materials, while sensing humidity, to move dial pointers, activate switches, or initiate some other mechanical action. Some of the organic materials used include: human and synthetic hair, animal membrane, paper, and wood. These humidistats can lack the precision and reliability required for critical humidity control. State-of-the-art electronic devices, being used increasingly in environmental control applications, employ materials with electrical resistance or capacitance that varies in proportion to humidity changes. The changes in humidity are accurately represented by changes in the electronic circuit characteristics of the instrument. Important HVAC terms, concerned primarily with dehumidification, are defined as follows:

(1) Dehumidification - The process of removing water vapor from air.

(2) Dehydration or drying - The process of removing water from any substance.

(3) Sorption - The process of taking and holding a substance by either absorption or adsorption.

(4) Absorption - The process of extracting one or more substances from a fluid (air or liquid) by the holding or combining action of a special material called an absorbent.

(5) Adsorption - The process of extracting one or more substances from a fluid b the adherence of those substances to the surface of a special material called an adsorbent.

5.2.7 Pressure. Pressure is an important parameter in environmental control engineering. Knowledge of the following basic types of pressure measurement is essential in understanding the environmental control of a communications/data processing facility.

5.2.7.1 Atmospheric pressure. The earth’s atmosphere, which ranges from about 100 to 150 miles in thickness, exerts a force (weight) on the earth’s surface. This force, called atmospheric pressure, is expressed in pounds per square inch (psi), inches of mercury column, or kilo Pascals (kPa). At sea level, a pressure of 74.7 psi (101.33 kPa) is referred to as standard atmospheric pressure. Other accepted parameters of the standard atmosphere at sea level are a barometric pressure of 29.921 inches of mercury and a temperature of 59 °F (15 °C).

5.2.7.2 Absolute pressure and gauge pressure. In environmental control, it is important to understand the difference between absolute pressure and gauge pressure. Gauge pressure is pressure with respect to atmospheric pressure. Absolute pressure is the pressure with respect to a perfect vacuum, or the sum of gauge and atmospheric pressures.

5.2.7.3 Fluid flow pressures. The majority of environmental heating and cooling functions involve the movement of fluids, typically air water, and refrigerant coolants in conduit systems (ducts, pipes, etc.). for the convenience of measurement, the low pressure of air movement in ducts is often expressed in the unit, inches of water. When air is circulated through a duct system during heating or cooling, fans provide the force necessary to move the air. The amount of air movement is measured as pressure within the ducts. Two types of pressure can be measured, typically in inches of water (or other liquid), using a device called a manometer. This device is connected to the duct in one of two ways, as shown on figure 2. On figure 2a, the manometer measures the static pressure of moving air. When there is no air movement, both sides of the manometer will be subject only to atmospheric pressure, and the levels will be the same. When air is being moved by the circulating fan, the presence of static pressure in the duct will be indicated by a rise in the liquid level of the right side of the manometer. A static pressure of two inches is shown in the figure. In the second type of installation, shown on figure 2b, the total pressure is being indicated (3 in). Total pressure is the sum of the static pressure and velocity pressure. The force of the air velocity creates the velocity pressure. The resistance of the duct network to the flow of air is overcome by the static pressure. Design engineers calculate the amount of resistance in a duct system in terms of static pressure. The flow of water in a network of pipes is also described by its pressure. In addition to static and velocity elements, the total pressure may have an elevation component, attributed to the weight of a column of liquid in vertical piping. Elevation pressure is negligible in air flow and is generally ignored. It is common practice to express liquid pressure in units of length, called head. Static head, velocity head, and elevation head represent the weight of the column of the liquid which the pressures would support. The purely linear head units are derived by cancelling out the mass/weight terms from a pressure expression.

5.2.8 Psychometrics and the psychometric chart. Psychometrics may be defined as the determination of the thermodynamic properties of moist air and the application of that knowledge for analysis and problem solving. Psychometric charts are valuable tools used by environmental control engineers. These graphical charts permit the direct reading of seven parameters of moist air, given enough information to establish a reference point on the chart. For example, a reference point could be established with dry-bulb and wet-bulb temperatures. The seven parameters are:

- Dry-bulb temperature
- Wet-bulb temperature
- Relative humidity
- Specific humidity
- Dew point temperature
- Total heat (enthalpy)
- Specific volume (volume per unit weight)

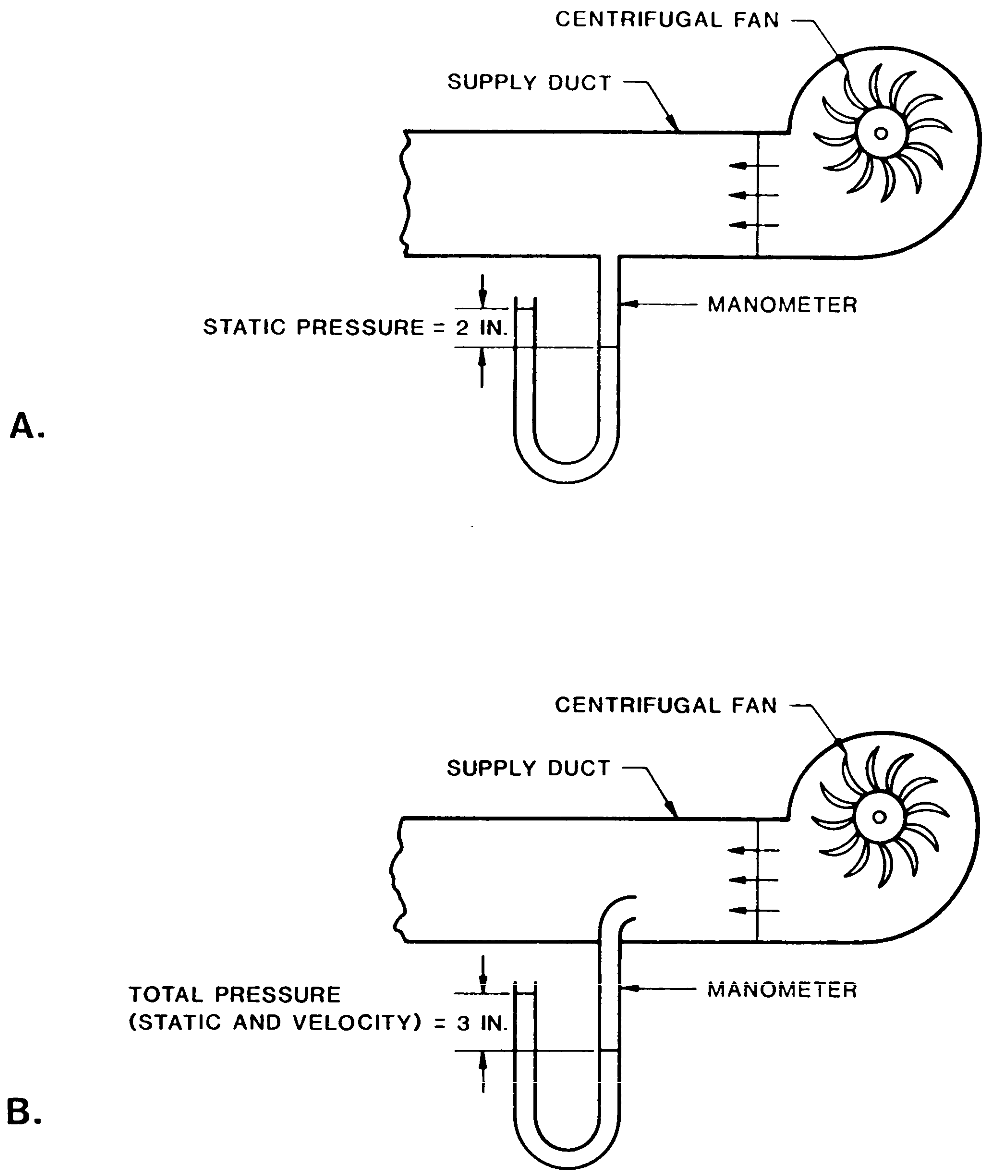


FIGURE 2. Manometer measuring air pressure in ducts.

ASHRAE has developed five psychometric charts to cover various altitude (pressure) and temperature ranges. See Table III.

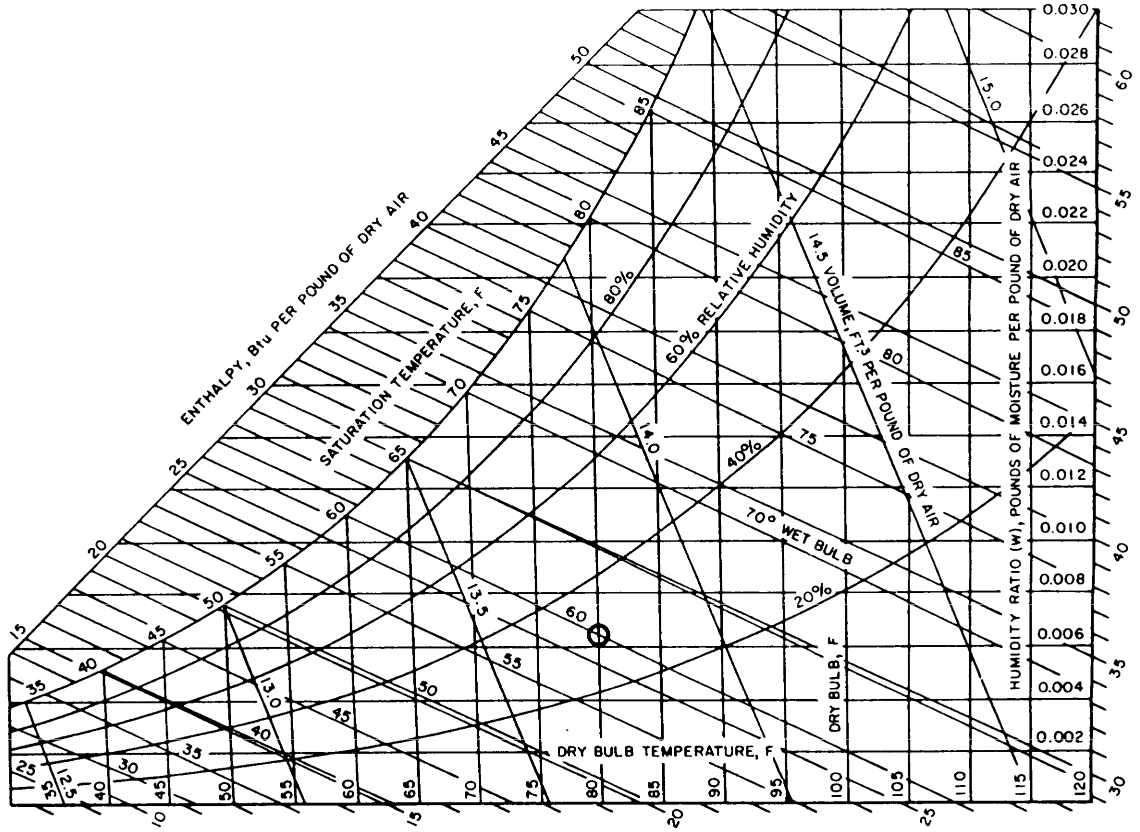
TABLE III. Altitude and temperature psychometric charts.

CHART	ALTITUDE	TEMPERATURE
1	sea level	normal
2	sea level	low
3	sea level	high
4	5000 ft	normal
5	7500 ft	normal

Figure 3 contains an illustration of a psychometric chart with an example of how a set of parameters is obtained.

5.2.9 Personal comfort and health. Properly designed and operating HVAC systems are essential in the work place for the maintenance of personnel comfort and the protection of individual health. A number of physiological and psychological factors must be considered in the engineering of HVAC systems for a DoD facility. These factors include the effects of: temperature, humidity, noise, air cleanliness, air quality, and even work station appearance and size. This section addresses the major factors which contribute to personal comfort and health, and identifies the environmental conditions that must be maintained.

5.2.9.1 Indoor air quality. Indoor air quality (IAQ) is discussed throughout this volume, but personal comfort and health are inextricably linked to IAQ. It is estimated that most people spend some 80 to 90 percent of their time indoors, which relates to mounting evidence that the indoor environment is responsible for many persistent health problems. Odors are the most dominant complaint affecting personal comfort, and even when not harmful to health, can adversely affect job performance. Figure 4 illustrates how pollutants can enter the indoor environment. The most prevalent pollutants are carbon monoxide and carbon dioxide. Smoke, radon gas, chemical fumes, and bacteria can also present serious health problems. Recent research on the “sick building” syndrome has established a “ relationship between interior carbon dioxide levels and complaints involving IAQ. Work station carbon dioxide levels of 500 to 800 parts per million (ppm) seem to characterize “sick buildings.” Since carbon dioxide is an exhalation product of human respiration, levels increase at poorly ventilated work stations and remain stable in well-ventilated areas. Carbon dioxide concentrations are relatively constant outdoors, so a comparison with indoor levels at a particular facility is useful in determining outdoor air being introduced through the HVAC system. Tests for interior carbon dioxide levels may also act-as an indicator for other indoor air contaminants, such as those related to building materials and furnishings. Infrared analyzers can be used to dynamically determine concentrations of several gases and vapors in ambient air by measuring infrared absorbance of wave lengths that characterize gases, such as carbon dioxide, carbon monoxide, and formaldehyde. Table IV lists common indoor pollution sources and the effects on personal health and comfort.



HOW MOIST AIR PARAMETERS ARE OBTAINED

ASSUME THAT PSYCHROMETER TEMPERATURES OF 80° F (DBT) AND 60° F (WBT) HAVE BEEN READ. THE STARTING POINT IS THE INTERSECTION OF THE TWO STRAIGHT TEMPERATURE LINES FOR THESE VALUES. (CIRCLED ON CHART)

TO FIND	ACTION
HUMIDITY RATIO (W)	MOVE HORIZONTALLY TO THE RIGHT AND READ 0.0064 FROM W SCALE
RELATIVE HUMIDITY (RH)	INTERPOLATE AND READ 30% BETWEEN THE 20% AND 40% RELATIVE HUMIDITY CURVES
SPECIFIC VOLUME (SP VOL)	INTERPOLATE AND READ 13.75 FT ^{3}/LB OF DRY AIR BETWEEN THE 13.5 AND 14.0 LINES
DEW POINT TEMPERATURE (DPT)	MOVE HORIZONTALLY TO THE LEFT AND READ 45° FROM THE SATURATION TEMPERATURE CURVE
ENTHALPY (H)	INTERPOLATE AND READ 25.8 Btu/LB BETWEEN THE 25 AND 26 ENTHALPY LINES WHICH RUN DIAGONALLY DOWNWARD, LEFT TO RIGHT

FIGURE 3. Psychometric chart.

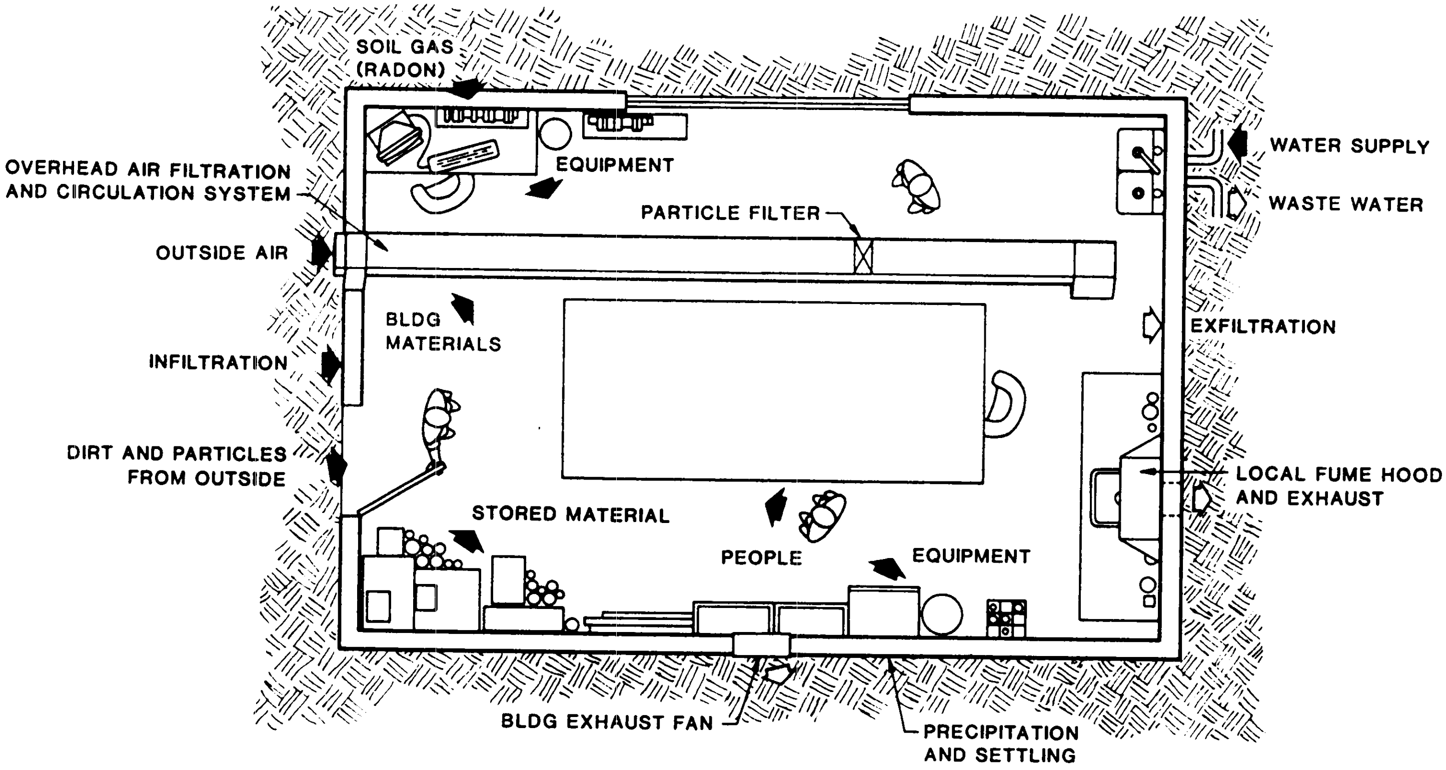


FIGURE 4. Pollutant entry and removal.

TABLE IV. Indoor pollution sources

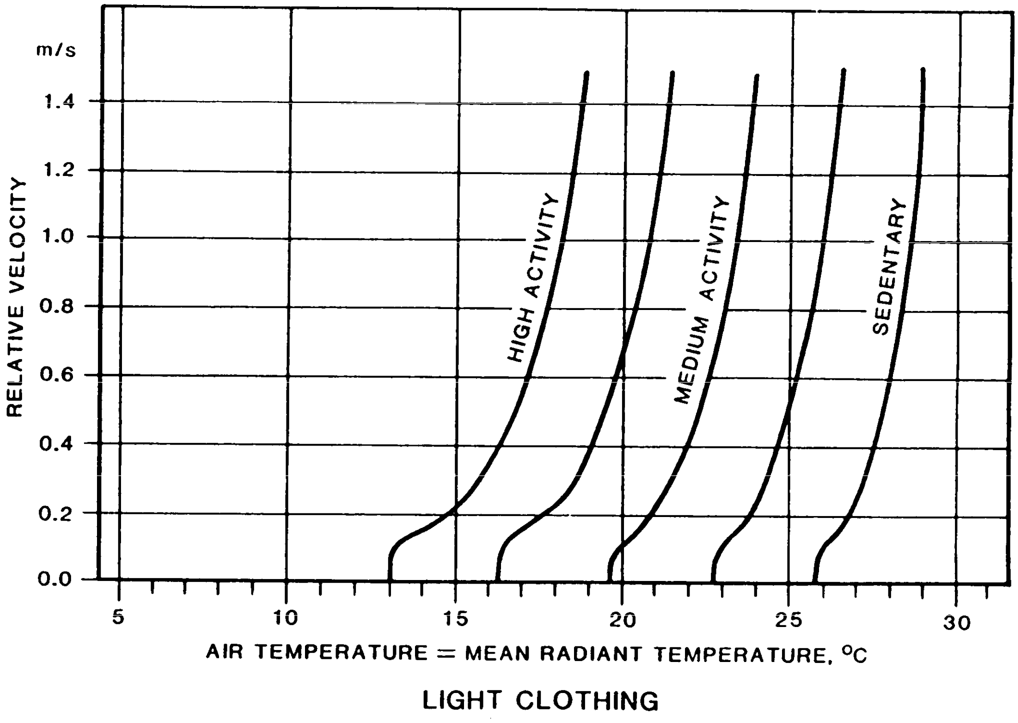
Pollutant	Source	Effect
Asbestos	Pipe and air duct insulation	Carcinogenic
Radon	Building materials from rock and soil and uranium ore deposits under the site itself	Carcinogenic
Vinyl chloride	Most plastics	Carcinogenic
Environmental tobacco smoke (ETS) (benzopyrene)	Smokers and ventilation systems that mix smoking area air with nonsmoking area air	Nasal and eye irration, offensive odors, respiratory problems
Carbon dioxide	People	Stale air complaints
Carbon monoxide and nitrogen dioxide	Fossil-fueled heaters and engines--parking garages	Nausea, dizziness, serious health problems
Formaldehyde	Certain foam insulations, paneling, plywood and other building materials	Fatigue, dizziness, general health
Ozone	Aerosols, photocopy machines, dc motors	Respiratory problems
Excess humidity	HVAC equipment, round moisture and building leaks	Rot fungus mildew, unpleasant feeling
Trichloroethylene (TCE), Trinitrofluorenone (TNF)	Copying machines, correction fluids	Offensive odor, respiratory problems

5.2.9.2 Standards that affect indoor air quality. Most complaints on the indoor air quality aspect of personal comfort can be resolved by changingthe amount of outside air (OA) introduced by the HVAC system (dilution). Other methods frequently used solely, or in combination with dilution, include source removal, local exhausts, and air treatment to remove contaminants (filtration). in the absence of specific ventilation criteria from the National Institute of Occupational Safety and Health (NIOSH), or the Occupational Safety and Health Administration (OSHA), ventilation codes within the United States are based on ASHRAE Standard 62, Ventilation for Acceptable Indoor Air Quality. This standard, before maximum energy conservation became popular, cited minimum and maximum OA rates per person. During the energy crisis of the early 1970's, the minimum OA quantity also became the maximum. The current version of ASHRAE Standard 62 lists the minimum OA rate as 15 cfm (7.1 L/s) per person (see 5.5.2.1). A comfortable temperature for the work station is very important. ANSI/ASHRAE Standard 55, Thermal Environmental Conditions for Human Occupancy, covers the thermal environmental conditions for humans. Proper maintenance of HVAC systems is crucial to the avoidance of molds and pockets of contaminants. ASHRAE Standard 52, Methods of Testing Air-cleaning Devices Used in General Ventilation for Removing Particulate Matter, outlines test methods on particulate filters to ensure their performance. ASHRAE Standard 84, Method of Testing Air-to-air Heat Exchangers, provides related test methods for the heat exchanger method of providing OA on an energy-efficient basis.

5.2.9.3 Other personal comfort and health factors.

5.2.9.3.1 Temperature and humidity. Relative humidity plays an important role in personal comfort and health. Its effects are closely related to the accompanying temperature. As the surrounding temperature increases or decreases, the body automatically adjusts its metabolic rate and blood flow near the skin surface. At higher temperatures, the body also attempts to cool its surface area by the evaporative action of perspiration. As the humidity increases, the cooling effects of perspiring are reduced, and discomfort increases accordingly. Figure 5 includes two graphs which show optimum comfort lines for personnel engaged in five levels of activity, while wearing light or medium clothing. The comfort lines are used to determine design comfort temperatures for given air velocities. The mean radiant temperature is defined as the uniform surface temperature with which a person exchanges the same heat by radiation as in the actual environment. Increased air movement lowers comfort tolerance to cold temperatures (wind chill effect) and raises comfort tolerance to higher temperatures. As already indicated, adequate ventilation is essential for personal comfort and reliable equipment operation. Excessive air movement in the workplace can cause discomfort to occupants. Air movement of approximately 50 ft/min (0.254 m/s) is considered to be comfortable for most individuals.

5.2.9.3.2 Noise. For the purposes of this handbook, noise may be defined as unwanted sound. It must be at high levels to cause physical discomfort, but its presence at lower levels can produce unwanted psychological effects, such as distraction and irritation. Sound power, pressure, and intensity are measures of sound energy. Sound power is the measure of a sound at its



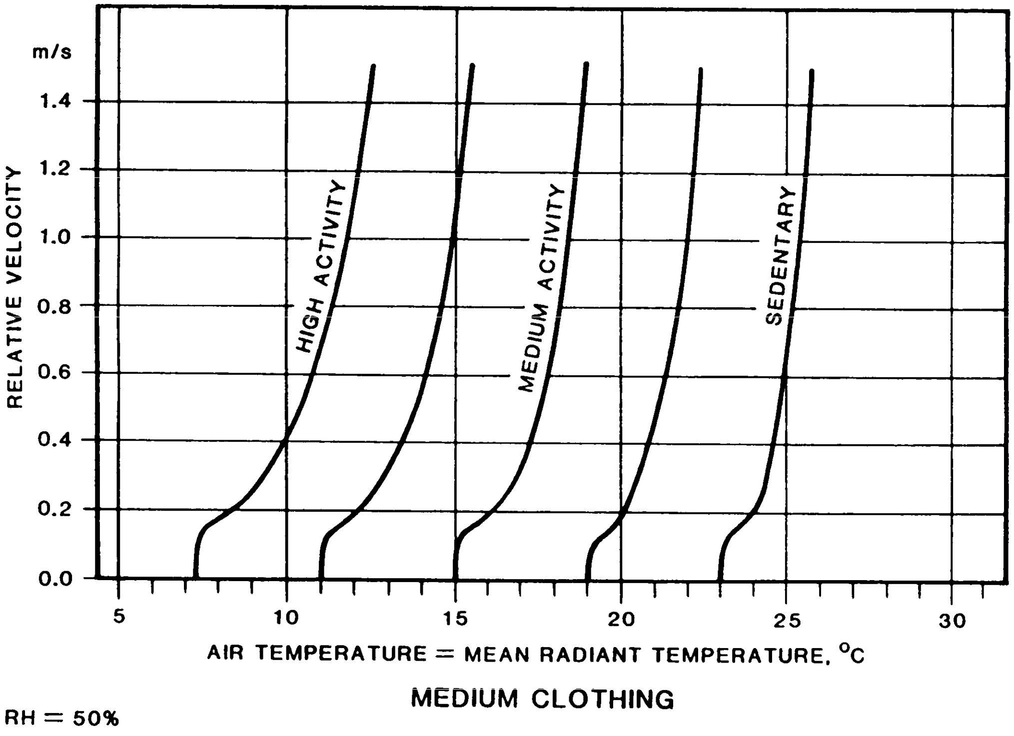


FIGURE 5. Effects of temperature and air velocity on personal comfort.

source. The watt is the unit of sound power. The level of sounds, which can be heard by the human ear, extends over a wide range, making the use of watts an awkward task. Therefore, the logarithmic decibel (dB) scale is used to quantify sound power levels. The decibel represents the ratio of the power of a given sound to the internationally recognized standard of one picowatt (10-12W). Sound pressure is used to measure sound at locations away from the source. Sound pressure is expressed in micropascals (uP), with 20 μP recognized as the threshold of hearing. Sound pressure level measurements use the dB scale, with 20 μP as the reference. Sound intensity uses watts per m^2 as its unit of measurement, and has essentially the same uses as sound pressure. The loudness of a sound is a subjective value perceived by the listener. Sounds with the same power, but different frequencies, are perceived to have different levels of loudness. The loudness of sounds are quantified by comparing them to a standard (1000-HZ tone) and are expressed in acoustic units called phons. One phon is the loudness of a 1000- Hz tone at 1 dB. Because the phon relates directly to dB, the scale is a nonlinear curve. A sound of 50 phons is not twice as loud as a sound of 25 phons. For comparing the loudness of sounds, an acoustic unit called a sone is used. One sone is defined as the loudness of a 1000-HZ tone at 40 dB. A loudness of 2 sones is twice as loud as a loudness of 1 sone. The concepts of noise criteria (NC) and room criteria (RC) are used by ASHRAE to express noise levels, as they relate to human comfort. Figures 6 and 7 show NC and RC curves which indicate noise levels for given-frequency ranges. Values of NC and RC above 35 are generally considered to be at the threshold of interference with speech understanding. The NC concept, which was conceived first, has some shortcomings, in that its application can produce conditions that are either too quiet or contain undesirable background noises. The RC concept is particularly useful in situations involving environmental control, where some background noise is desirable to mask equipment or other sounds. The selection and positioning of power production and environmental control equipment must take into account the creation of unwanted noise. Sound level meters measure noise using weighted scales which approximate human frequenqy response at various sound pressure levels. The A-scale, used extensively in HVAC noise measurements, approximates human frequency response to sound pressure levels in the 20- to 30-dB range. At these low sound levels, sensitivity of the ear to low frequencies is poor. The A-scale uses dBA levels, which are typically five higher levels than equivalent RC levels. The B-scale (dBB) a proximate human frequency response to sounds in the 60- to 70-dB range, while the C-scale (dBC) reflects response to loud sounds in the 90- to 100-dB range.

5.2.9.3.3 Overall appearance. The overall appearance of the workplace contributes to the attitude and comfort of personnel. In addition to the provision of proper lighting levels, addressed in 5.5.5, pleasing colors and shapes are important. The psychological aspects of facility design are not within the scope of this handbook.

5.2.10 Heat generation, removal, and control. Because of the major role that heat plays in environmental control, it is appropriate to discuss some of its attributes. Heat may be defined, in simple terms, as the motion of atoms or molecules in a material, manifesting the presence of energy in that material. In environmental control, heat is considered to be present in three forms: sensible heat, latent heat, and radiant heat.

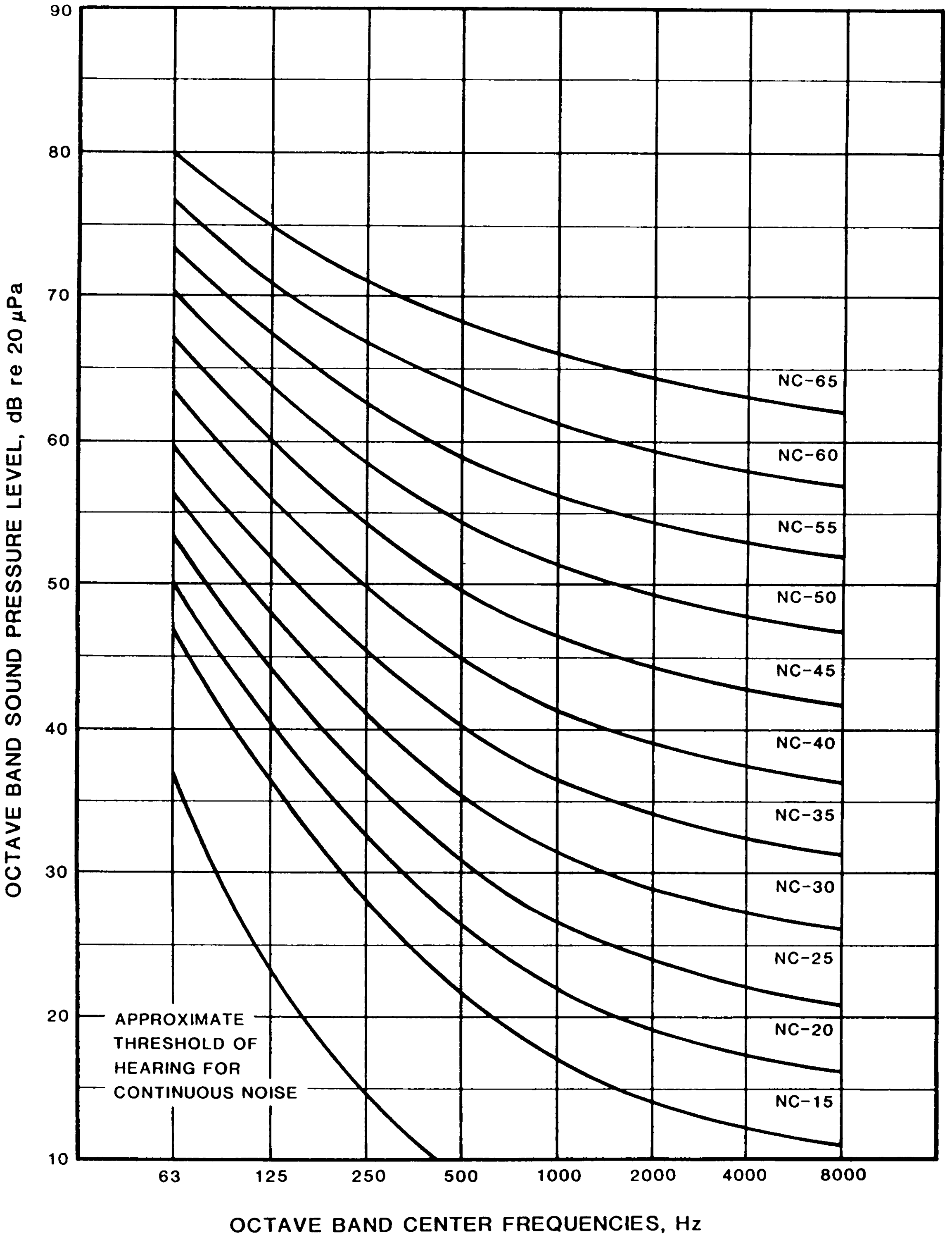
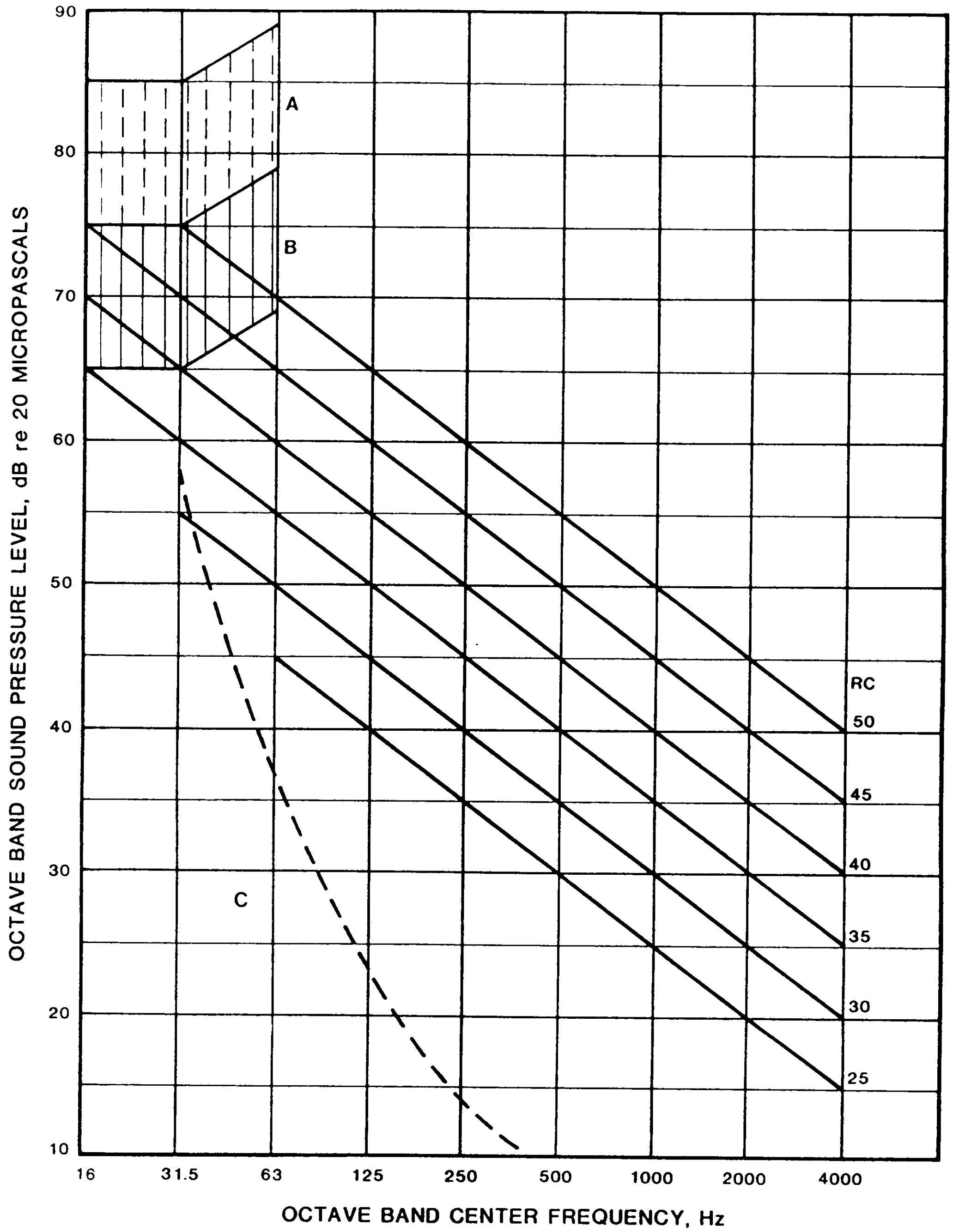


FIGURE 6. Noise criteria chart.



REGION A: HIGH PROBABILITY THAT NOISE-INDUCED VIBRATION LEVELS IN LIGHTWEIGHT WALL AND CEILING CONSTRUCTIONS WILL BE FELT: ANTICIPATE AUDIBLE RATTLES IN LIGHT FIXTURES, DOORS, WINDOWS, ETC.

REGION B: NOISE-INDUCED VIBRATIONS LEVELS IN LIGHTWEIGHT WALL AND CEILING CONSTRUCTIONS MAY BE FELT: SLIGHT POSSIBILITY OF RATTLES IN LIGHT FIXTURES, DOORS, WINDOWS, ETC.

REGION C: BELOW THRESHOLD OF HEARING FOR CONTINUOUS NOISE.

FIGURE 7. Room criteria chart.

5.2.10.1 Types of heat.

a. Sensible heat is defined as a basic, physical property of a material, caused by its molecular motion, which can be measured as Btu/lb of dry air above an arbitrarily selected value, generally 0 °F. As molecular activity increases, more heat is produced, and a higher temperature is observed.

b. Latent heat is related to the presence of water vapor and represents the energy required to remove the water vapor. It is also measured as Btu/lb of dry air above the same value point as sensible heat, so they can be added together to give total heat.

c. Radiant heat is actually infrared radiation, and not the result of molecular motion. Radiant heat is given off by objects which have a higher temperature than their surroundings. Dull black objects are the best emitters and absorbers of radiant heat, and light-colored or shiny objects are the poorest. The radiant heat received by exposed objects in the surroundings is converted to sensible heat in those objects, as the result of increased molecular motion. The heat is transmitted by radiation, which is the emission of energy-carrying electromagnetic waves (see 5.2.10.2c).

5.2.10.2 Heat transfer. In HVAC functions that involve heat, it is often necessary to move heat from one area to another. These functions might be heating a building space, removing heat to cool an area, or adjusting humidity levels. There are three modes of heat transfer: conduction, convection, and radiation.

a. Conduction is the mode in which sensible heat is transferred when bodies or materials with different temperatures come in contact with one another. The higher rate of molecular activity in the warmer body transfers energy to the cooler material, resulting in increased molecular activity in the cooler material and a corresponding rise in its temperature. On a cold winter day, the indoor heat is transferred to the outdoors, through the building walls, by conduction. Similarly, a radiator heats the surrounding air by conduction.

b. Convection is the mode of heat transfer provided by fluids such as air or water. The medium is first heated by conduction, expands, and then rises because of its lighter density, causing currents which lead to areas of lower temperature. The heated medium transfers its energy to the area of lower temperature by conduction. The transfer or movement of heat from the central source to the area of lower temperature is considered to be the convection process. An example of convection heat transfer is the column of warm air rising above a hot water or steam radiator.

c. Radiation is different from conduction and convection in that it does not require the presence of an intermediate material or substance to transfer heat. In the radiation process, heat is conveyed by electromagnetic waves in the infrared spectrum (between the EHF and visible light bands). The heat being conveyed is radiant heat, not sensible heat. Radiation heat transfer acts similarly to light transmission, in that it is unaffected by gravity and moves equally well in all directions. The capacity of a material to emit radiation is called emittance. The capacity to absorb radiated energy is called absorbance. These two values are ratios of the capacities of the material to those of an ideal black body, at the same temperature. The amount of energy that can be transferred is a function of the emissivity and absorptivity of the materials involved, the angle of incidence, and the fourth power of the absolute temperature differential.

5.2.10.3 Heat measurement. The standard units for the measurement of heat are the British thermal unit (Btu) in the U.S. or English system, and the calorie (cal) in the metric system. The Btu is still used extensively in U.S. construction. The units of the metric system that are being adopted as the worldwide standard are correctly called the International System of Units (SI). A table of English/metric conversions is included in appendix A, Table VIII. A Btu is defined as the amount of heat that must be added to, or subtracted from, one pound of water at 60 °F to produce a temperature increase or decrease of 1 °F. A calorie is defined as the amount of heat that must be added to, or subtracted from, one gram of water at 15 °C (Celsius or Centigrade) to produce a temperature increase or decrease of 1 °C. The amount of heat required to change the temperature of a unit sample of a material or substance 1 degree is called the specific heat (SP HT) of that substance and is expressed as Btu/(lb x °F) or kJ/(kg x °C). (Kilojoules are formed by multiplying the number of calories by 4.19.) For example, the specific heat of air at normal room temperatures is 0.241 Btu/lb. As stated above, environmental control functions often involve the movement of heat. The rate of heat flow is, therefore, of major importance. Heat flow is expressed in Btu per hour (BH) or watts (W). One Btu/hr equals 0.293 watts. The total heat flow of moist air in Btu per hour (BHT), is the sum of the sensible heat flow in Btu per hour (BHS) and the latent heat flow in Btu per hour (BHL):

$$BHT = BHS + BHL$$

5.2.10.4 Heat losses and gains in buildings. The continuing escalation of energy costs and the recurring threat of shortages mandate that building designs minimize unwanted heat gains and losses. Recently, building designers have taken energy conservation into account as standard practice. For example, buildings are now being well insulated in hot weather locations to reduce cooling loads. Previously, it was often deemed necessary to provide effective insulation only in the colder regions. The cosmetics of building design are now being tempered with energy conservation as a goal. Using data gathered during the site survey, the characteristics of the local climate, including temperature levels and changes, moisture levels (rain and snow), and wind velocity and direction, must be incorporated into the design features.

5.2.10.4.1 Heat losses. During cold weather, most building heat losses fall into either of two types - transmission losses and infiltration losses. the first type, indoor heat escapes to the colder exterior by sensible heat transfer through walls, windows, ceilings, and floors. In infiltration losses, colder outdoor air that enters the building through open doors and windows, and structural leaks, must be heated to the desired indoor temperature. Outdoor air that is brought into the building for ventilation purposes must also be heated, just as if it were an infiltration loss. Infiltration and ventilation losses involve both sensible and latent heat. The energy required to raise the temperature of the outdoor air to the indoor level is in the form of sensible heat. Energy required to add moisture to the outdoor air is in the form of latent heat. Estimated building losses are expressed in Btu/hr or watts (1 Btu/hr = 0.293 W)

a. Transmission losses. In calculating the amount of heat, or heat load, that will be required to maintain the planned indoor temperature ranges, weather data and building design parameters must be carefully related. Once some preliminary decisions have been made on the architectural design, the parameters of the indoor and outdoor climates are brought into the detailed planning. Desired temperature and humidity levels must first be established for all internal building areas and spaces. These levels may vary significantly between spaces occupied by personnel and areas of limited access, such as crawl spaces and storage rooms. Indoor climate parameters for electronic equipment are specified by the manufacturer. Consideration should be given to allocating building space on the north walls for activities, such as power generation and supply storage, which do not require critical temperature control. The effects of outdoor temperatures and wind conditions on exposed exterior surfaces will influence the positioning of doors and windows, and the types of construction materials and structural techniques that are used. For example, heavily used building entrances should be located away from the path of cold winds. The amounts of heat lost through transmission to the outdoors and areas of lower temperature will vary with the types of construction materials used for the exposed surfaces. How transmission losses are measured is explained below.

b. Infiltration losses. Greater energy consciousness in recent years has reduced the potential for infiltration losses through improved construction techniques. Infiltration is caused by differences in air pressure through the external shell or envelope of the building. These pressure differences are the result of wind and temperature. During colder weather, warm indoor air tends to flow upward inside the building, escaping near the top, and causing colder outside air to infiltrate near its base. This phenomenon called the “stack effect”, is illustrated on figure 8. The neutral level will be near the vertical center of the building, when wind effects are minimal and openings in the building shell, which allow infiltration, are evenly distributed. The presence of chimneys, stairwells, elevator shafts, utility ducts, and other vertically oriented spaces influences the position of the neutral point and complicates the calculation of heat losses. Cold air infiltrates through open doors and windows, and around their perimeters. Other openings in the building shell, such as cracks, loose fitting joints, and ductwork, are sources of infiltration. Outside air, which is brought into a building by ventilation systems, is also a form of infiltration. Prevailing winds create positive pressure on the windward side of a building, driving in the outdoor air, and negative pressure on the leeward side,

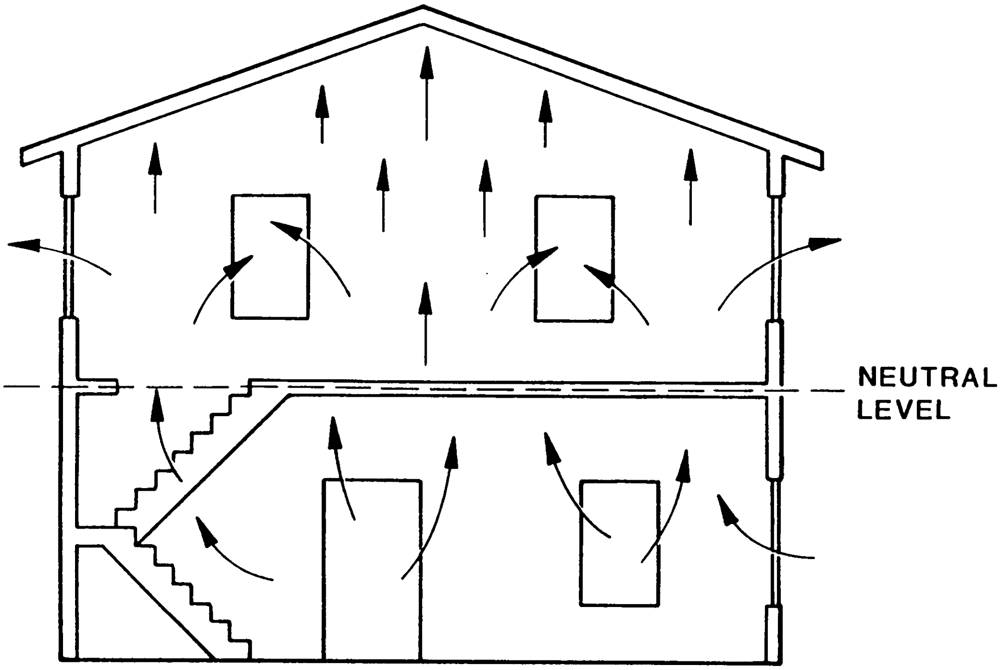


FIGURE 8. Stack effect.

causing indoor air to flow outwards. As previously stated, improvements in construction have created "tight buildings" with reduced infiltration losses. A disadvantage of tight buildings is that the interior air can become contaminated more quickly, since less fresh air is infiltrating. This shortcoming can increase the requirement for ventilation. The elements of ventilation, including the use of energy-efficient heat-transfer techniques, are discussed in a separate section.

5.2.10.4.2 Heat gains. Heat gains within buildings can significantly influence the design of the cooling system. The presence of large heat gains may reduce the amount of heating required during cold weather, and conversely, increase the need for cooling in the moderate or high temperature areas. Heat gains are expressed as the rate that heat is entering or being generated in a room or space. They are categorized by source and type of heat (sensible versus latent). There are a number of sources of heat gain (cooling load):

a. Solar radiation on exposed surfaces and through windows, if any.

b. Heat conduction through exterior walls and roofs.

c. Heat conduction through interior walls, ceilings, and floors.

d. Heat generated by equipment, personnel, lighting, and appliances.

e. Heat transferred by the outside air through infiltration and by ventilation systems.

In warm weather, the flow of air within a building due to the stack effect is downward, opposite in direction from the flow in cold weather (see 5.2.10.4.l.b). The stack effect on cooling requirements is usually a concern only in tall buildings (more than five stories). The second category, type of eat, is a determining factor in the selection of cooling equipment. Heat introduced by conduction, convection, and radiation from any source is in the form of sensible heat. Moisture that is introduced into the space adds latent heat gain. The personnel in a room, for example, are a source of both sensible heat and moisture. Excess moisture must be condensed out of the air during the cooling process. Cooling equipment is rated according to its ability to remove both sensible and latent heat.

5.2.10.5 Controlling heat losses and gains. An important early consideration in controlling potential heat losses and gains in a facility design is complete and accurate climatic data. Again, these data should be gathered during the site survey. Controlling heat losses and gains is accomplished through architectural design, including landscaping, and types of construction materials and techniques used. Even the selection of mission and mission-support equipment may be influenced by heat loss and gain considerations. The geographical location of the facility will influence the solar orientation of the building, and the utilization of solar energy. The predictable amount of solar radiation will affect the size and location of windows, and the amount of roof overhang. Temperature extremes, both high and low, will influence the selection of construction materials and techniques for their insulating qualities. The importance of insulation in controlling heat gains and losses cannot be overemphasized. In locations where sunshine is abundant, it may be possible to use solar energy for some heating in periods of cold weather. The effective period of the low winter sun is between 9:00 a.m. and 3:00 p.m. In the northern hemisphere, the south side of buildings receives the most sun. The presence of windows in DoD facilities is generally limited because of security considerations. However, where windows are included in a building design, they can present unique opportunities to use solar energy. Solar radiation entering an indoor space through windows can provide winter heating at minimal cost. Solar building designs usually incorporate some form of heat storage and heat transfer. Heat storage can be as simple as the use of ceramic tile floors or as sophisticated as the employment of complex heat mass devices and elaborate circulation systems. Conversely, during the summer months, controlling the exposure of southerly oriented building surfaces to the sun may be needed. A simple solution to the summer heating problem is the use of a roof overhang to block the high summer sun, as shown on figure 9. Unwanted direct sunlight through windows can be blocked from indoor spaces by protective coverings, both indoor and outdoor. Entire external building surfaces can be shaded by carefully positioned trees. The planting of deciduous trees for summer shading has the additional advantage of allowing the warming winter sun to reach the building surfaces. Trees and other vegetation also provide excellent protection against undesirable winds. Positioning buildings in the shelter of other structures or hills can also provide effective protection from prevailing winds.

5.3 Site survey environmental factors. Ideally, a communication/data processing facility has a number of candidate sites from which the best location is chosen. The selection of the best geographical location will be made after analysis of site survey data obtained for each of the candidate sites. However, when real estate availability is critical, as is often the case, only one location may be made available, typically on a U.S. or Allied Government or military installation. Once the location is established, comprehensive and detailed information on the climate, geographical features, site resources, local utilities, and other potential support activities must be included in the site survey. This information is essential to the selection of the architectural design, building materials and techniques, and supporting power and environmental control systems.

5.3.1 Climate. There are several sources of climatic information for the United States, including agencies of the National Oceanic and Atmospheric Administration (NOAA), such as the National Weather Service and National Climatic Data Center. Within the DoD, triservice manuals containing engineering weather data (TM5-785, NAVFAC P-89, AFM88-29) are mandatory for use. Table V is an extract of this engineering weather data. Other excellent sources include local Governments, colleges, and universities. ASHRAE provides weather data for the United States and other countries based upon continuous observations from weather stations, airports, and U.S. Air

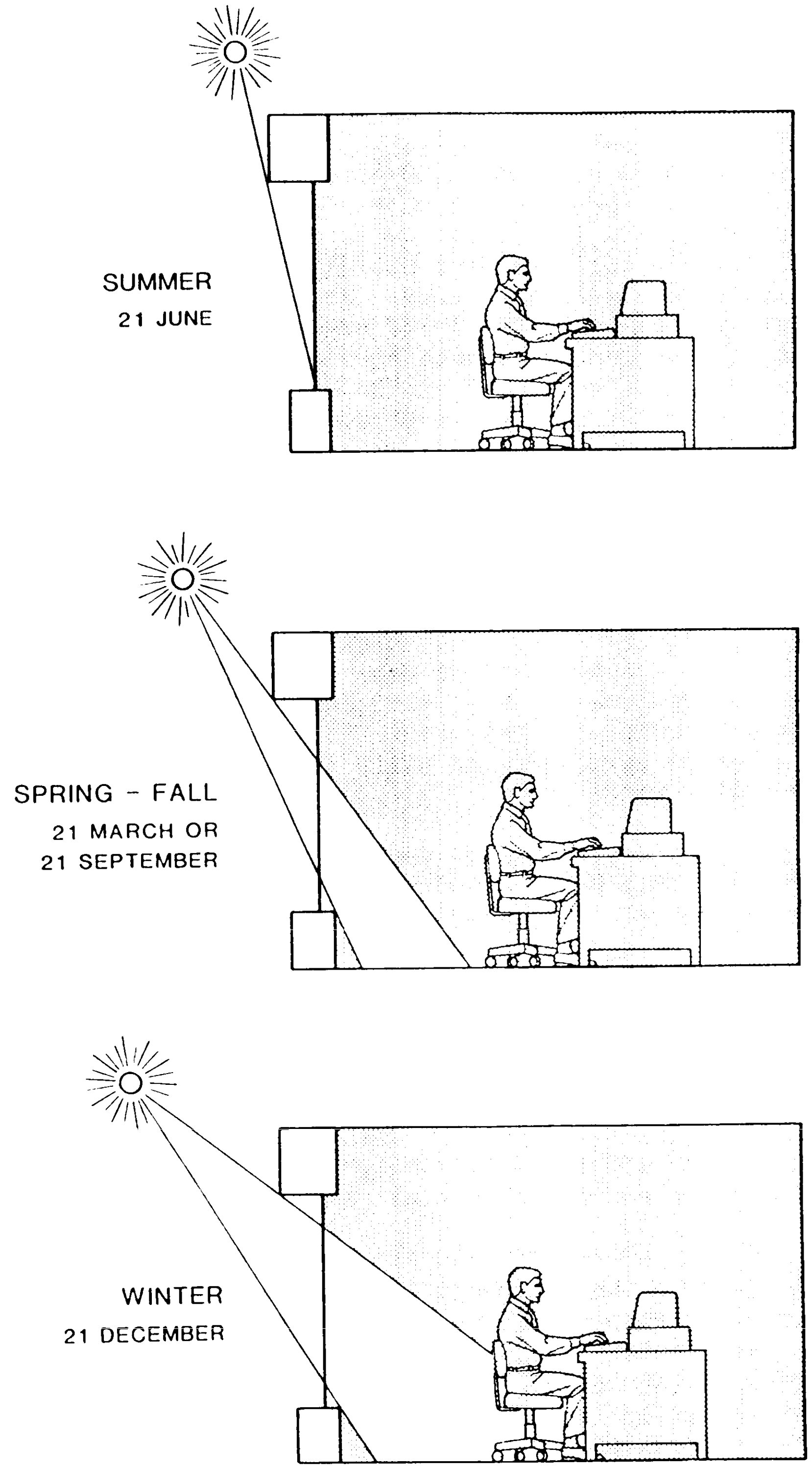


FIGURE 9. Controlling seasonal sun by roof overhang.

Table V. U.S. outdoor design conditions.

STATE Station	LOCATION Lat N	LOCATION Long W	Elev feet	WINTER DESIGN DATA HEATING Dry Bulb 99% F	97.5% F	Pvlg Wind dir	Mean Speed knots	DEGREE DAYS Heating annual	SUMMER DESIGN DATA AIR CONDITIONING Dry Bulb 1% F	MCWB F	2.5% F	MCWB F	Mean Daily Range F	Pvlg Wind dir	5% F	MCWB F	Wet Bulb 1% F	2.5% F	5% F	SUMMER CRITERIA DATA AIR CONDITIONING Dry Bulb 93 F hrs	80 F hrs	Wet Bulb 73 F hrs	67 F hrs
ILLINOIS																							
Chanute AFB	40 18	88 08	753	-4	1	W	10	5966	94	75	91	74	25	SSW	89	73	78	77	75	45	764	421	1386
Chicago/Midway Aprt	41 47	87 45	607	-5	0	NW	11	6127	94	74	91	73	23	SW	88	72	77	75	74	46	100	275	1111
Chicago/O'Hare Aprt	41 59	87 54	658	-8	-4	WNW	9	6497	91	74	89	74	24	SW	86	72	77	76	74	18	549	265	1028
Danville/Vermilion Co	40 12	87 36	695	-4	1	W	10	5538	93	75	90	74	24	SSW	88	73	78	77	75	36	714	421	1386
Decatur	39 50	88 52	679	-3	2	NW	10	5344	94	75	91	74	24	SW	88	73	78	77	75	46	793	421	1386

ANDREWS AFB, MARYLAND

Temperature Range	NOVEMBER Obsn Hour Gp 01 to 08	09 to 16	17 to 24	Total Obsn	M C W B	DECEMBER Obsn Hour Gp 01 to 08	09 to 16	17 to 24	Total Obsn	M C W B	JANUARY Obsn Hour Gp 01 to 08	09 to 16	17 to 24	Total Obsn	M C W B	FEBRUARY Obsn Hour Gp 01 to 08	09 to 16	17 to 24	Total Obsn	M C W B	MARCH Obsn Hour Gp 01 to 08	09 to 16	17 to 24	Total Obsn	M C W B	APRIL Obsn Hour Gp 01 to 08	09 to 16	17 to 24	Total Obsn	M C W B	ANNUAL TOTAL Obsn Hour Gp 01 to 08	09 to 16	17 to 24	Total Obsn	M C W B
100/104																																0		0	77
95/99																																5	1	6	76
90/94																											1	0	1	71		64	8	72	74
85/89																											5	1	6	66	0	189	54	243	72
80/84		1		1	69																	1	0	1	61		11	4	15	63	10	282	136	428	70
75/79		2	0	2	67																	4	1	5	60	1	13	8	22	61	88	296	247	631	68
70/74	1	6	2	9	61		1	0	1	59		1	0	1	59		0	0	0	58		8	3	11	57	2	19	13	34	58	318	270	337	925	66
65/69	4	14	5	23	58	0	4	1	5	58	0	1	1	2	58		2	1	3	57	1	9	5	15	55	11	29	24	64	56	337	229	292	858	61
60/64	8	31	17	56	55	3	7	5	15	55	1	3	1	5	55	1	3	2	6	55	4	15	10	29	52	20	36	30	86	53	292	218	245	755	56
55/59	19	42	28	89	51	6	13	7	50	50	3	5	4	12	51	2	10	6	18	50	7	19	17	43	48	29	39	36	104	49	255	207	226	688	51

State Station	Annual Cooling Degree Days
Pennsylvania	
Lancaster	826
Letterkenny Army Depot	793
Mechanicsburg	1025
New Castle	655

Force bases. Similar organizations exist in other countries. The following information must be gathered from engineering weather data manuals and the site survey:

a. Dry- and wet-bulb design temperatures.

b. Number of heating and cooling degree days.

c. Amounts of precipitation.

d. Direction and velocity of prevailing winds.

e. Number of days/hours of sunshine.

f. Lightning density.

g. Potential for unusual weather (tornado, hurricane, monsoon, sand storm, etc.).

Predictable weather parameters are called design conditions. Paragraphs 5.4.2.2.1 and 5.4.2.3.1 contain the recommended winter and summer design conditions, respectively, for DoD communications and data processing facilities. The DCA recommends using the engineering weather data contained in service manuals as the primary source of climatic data for DCS installation planning. The following design parameters are included:

5.3.1.1 Design temperatures. Winter dry-bulb temperatures (°F) are those which are equal or exceed 99 percent 97.5 percent of the time, during the coldest three consecutive months of the year. Summer dry-bulb and wet-bulb temperatures are those which are equalled or exceeded 1 percent, 2.5 percent, and 5 percent of the time, during the warmest four consecutive months. Mean coincident wet-bulb temperatures (MCWBT) are those which occur coincident with respective dry-bulb temperatures. Summer criteria data reflect the number of hours that the dry-bulb temperatures of 93 °F and 80 °F and the wet-bulb temperatures of 73 °F and 67 °F are equalled or exceeded during the warmest six consecutive months. Mean daily range data reflect the differences between maximum and minimum temperatures on those days that the 2.5 percent temperature is reached or exceeded.

5.3.1.2 Winds. Winter wind data show the prevailing direction and average speed occurring most frequently with the 97.5 percent dry-bulb temperature. Summer wind data indicate the prevailing direction occurring most frequently with the 2.5 percent dry-bulb temperature.

5.3.1.3 Degree days. A heating degree day is defined as the unit which represents a l-degree drop below the base temperature of 65 °F in the mean daily outdoor temperature. Cooling degree days are the mean annual number of degree days that the base temperature of 65 °F is exceeded. The table shows the mean annual number of degree days, based upon 30 years of records.

5.3.1.4 Other design parameters. The types of information listed above must be recognized as being generally statistical averages, and the localized effects of terrain features on the climate must also be taken into account. These localized effects might be temperature changes, amounts of precipitation, and the wind conditions brought about by the proximity of hills, mountains, or bodies of water. The types and densities of local vegetation can also have an effect on local climate.

5.3.2 Geographical features. In addition to the effects on the local climate, geographical features must be examined. Topography and soil conditions are important to the structural foundations of buildings, large equipment, and antennas. They also affect ground conductivity, selection of vegetation, water drainage, underground storage, and earth berming. Information on electrical system rounding is presented in Volume II of this handbook. The new or existing site may also have usable natural resources. These natural resources include the vegetation, sun, wind, and water.

5.3.2.1 Vegetation. In addition to cosmetic applications, vegetation is used to control soil errosion and the effects of solar radiation and winds. Trees are used effectively as natural wind breaks and to control sunlight on building surfaces. Deciduous trees can be positioned to block unwanted summer sunlight from exterior walls, while permiting winter sunlight to warm the building surfaces. Properly positioned trees can reduce sunlight and winds by as much as 90 percent. Building surfaces exposed to the sun can contain solar collection devices.

5.3.2.2 Solar energy. The energy crisis of the 1970's surfaced a long overdue concern over energy conservation. Solar energy is an abundant renewable resource in contrast to the nonrenewable fossil fuels such as coal, oil, and natural gas. In addition to the obvious uses of the sun for illumination, the active and passive application of solar energy should be evaluated. However, in many DoD electronic facilities, there is enough waste heat available to negate the need for solar-collected heat. A great deal of useful information on the uses of solar energy is now available, but is mostly devoted to heating applications. However, the use of solar-driven photovoltaic devices for power generation is expanding, especially in light of the reduced power requirements of integrated electronic circuitry. Figure 10 is a chart which shows the sun's hourly position with respect to the horizon, at specified latitudes. It is used to determine angles for solar collection or blocking.

5.3.2.3 Winds. Prevailing winds at a site can be harnessed for power production, using wind generators, as well as for effective cooling and ventilation. However, the presence of moderate and strong winds during winter can add to indoor heating loads, and can strongly influence building design. Information concerning wind generation of power is contained in Volume II. Effective use of prevailing winds is also discussed in section 5.5.2 concerning ventilation.

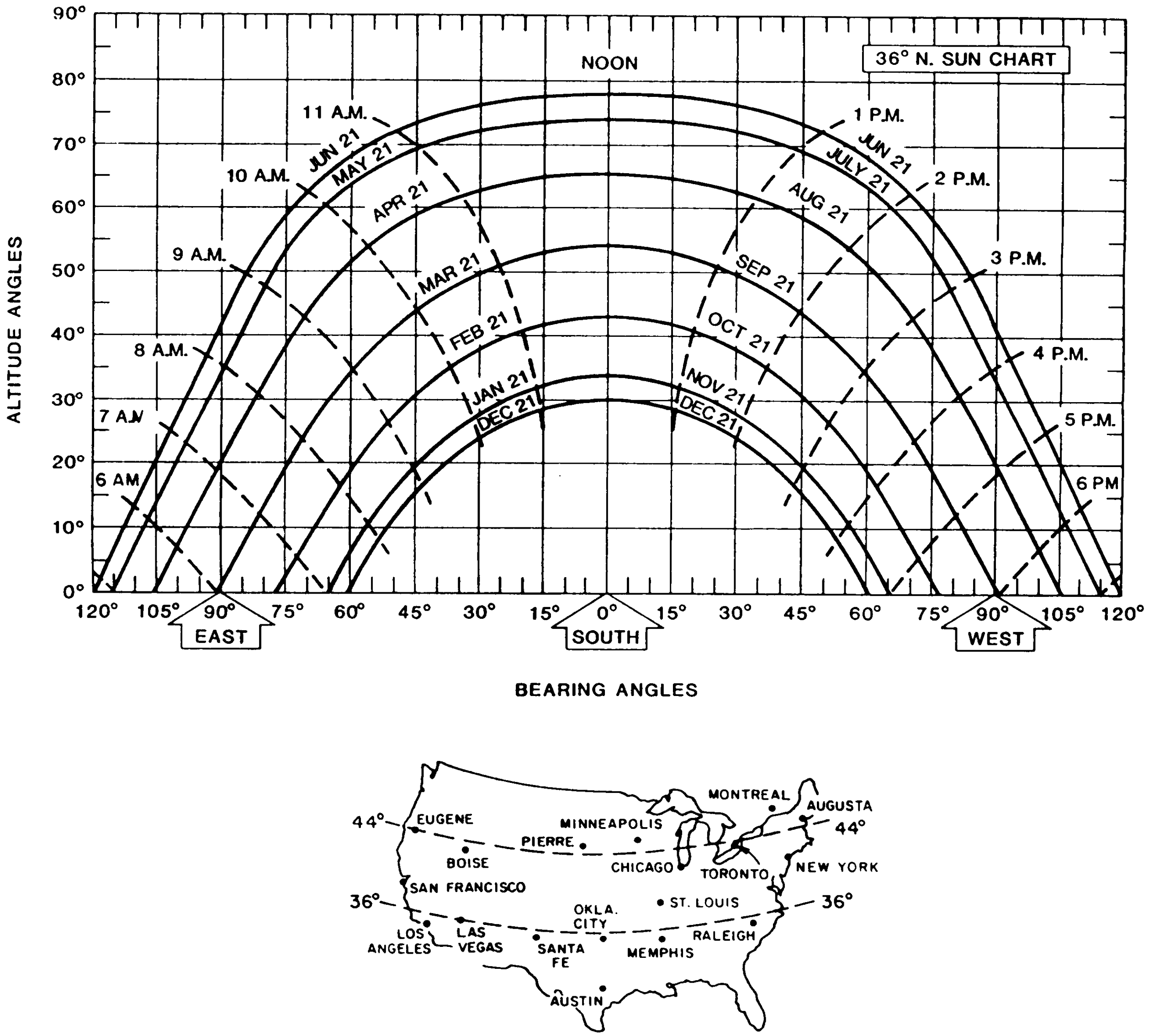


FIGURE 10. Sun position chart.

5.3.2.4 Water. Naturally occurring water at the site, generally identified as rainfall amounts and groundwater, may have special value as a potable water supply. Bodies of water such as lakes, ponds, rivers, streams, and oceans have potential application as heat sinks and heat sources.

5.3.3 Site resources. Where a new or retrofit facility will be collocated with other DoD or government activities, the exploitation of all existing on-base or on-post services and utilities should be investigated. The same holds true for other installations located convenient distances away. The site survey should identify and evaluate all potential support, such as utilities, maintenance, transportation, supply, storage, housing, food service, and recreational facilities.

5.3.4 Local utilities. In most areas of the U.S. and foreign countries, local utilities can be used for support. Locally provided e electrical power is the most important consideration and is addressed in detail in volume II. The decision to use local commercial or government-provided electrical power and the extent of backup systems will be based upon site survey data. The local availability and cost of coal, oil, and natural gas will be the determining factors in the selection of heating, cooling, and power generation equipment. Natural gas is considered to be an interruptible fuel source and is not usually suitable as a primary source for DoD facilities. The local water supply must also be evaluated for quality, cost, and reliability. The quality of the local potable water supply must meet U.S. standards.

5.3.5 Local support activities. Important local support activities include construction capabilities, equipment and building maintenance, transportation, communications, supply, housing, and recreation. The capabilities of local contractors and other service providers are important to future maintenance and support activities. The availability of materials, supplies, and labor are significant to both initial construction and sustained operations. Geopolitical climates of site locations should be evaluated because they affect the stability of local economies and governments. Such stability relates directly to the reliable delivery of utilities, goods, and services, especially in foreign countries.

5.3.6 Site survey engineering checklist. A checklist for ensuring the completeness of site survey data essential for the design phase of a DoD communications/data processing facility is provided in appendix D. This checklist should be used only to verify the completeness of site survey activity and information. It is neither a replacement for site survey functions nor a substitute for individual military department site survey checklists.

5.4 Building construction and design conditions. The architectural design and the type of construction used for a DoD communications/data processing facility are controlled by a number of factors. The basic controlling elements are the mission, climate, and available dollars. The design criteria must support the mission demands, while achieving a balance with the local climate and meeting cost constraints. Special construction considerations are art of fixed facility design criteria, which is the subject of 5.74. The thermal characteristics of the various types of building construction can have a significant impact on the selection of environmental systems, because so much of environmental control involves heat. The types of materials and the construction techniques used to build the facility greatly affect heat movement or transfer. Types of walls, doors, windows, floors, and ceilings should be chosen on the basis of how they affect heat transfer. Improvements in construction practices and materials are being made with consideration to their effects on energy use and the environment, as well as their cosmetic qualities.

5.4.1 Heat transfer properties. The commonly used parameters to classify the heat transfer (thermal) properties of construction material are: conductivity, conductance, and resistance. Continuing efforts to adopt the metric system notwithstanding, the use of the Btu in the U.S. construction industry remains extensive. Accordingly, the Btu will be used for discussions of heat flow in this handbook. English/metric conversion tables are provided in appendix A, Table VIII.

5.4.1.1 Conductivity. Conductivity (k) is defined as a measure of the ability of a homogeneous material or substance to transmit heat. Conductivity is commonly expressed in Btu per hour, per square foot of area of the material, per inch of thickness of the material, per degree Fahrenheit of temperature difference (At) on opposite surfaces of the material.

$$k = BH/ft^2/in/\Delta t$$

where BH equals Btu per hour.

5.4.1.2 Conductance. Conductance (C) is defined as a measure of the ability of a nonhomogeneous material to transmit heat. An example of a nonhomogeneous material is a concrete block, which has a composite structure of concrete and air, as shown in figure 71. The units of conductance are Btu per hour, per square foot of area of the wall, per degree of temperature difference (At) on opposite surfaces of the material.

$$C = BH/ft^2/\Delta t$$

where BH equals Btu per hour.

It is important to note that conductance is not expressed for a unit thickness of a material, but rather for the actual thickness of construction or fabrication.

5.4.1.3 Resistance. Resistance (R) is defined as a measure of the ability of a material or substance to impede or insulate the flow of heat. Therefore, it has a reciprocal relationship with conductivity (k) and conductance (C). Resistance measurements are applied to both homogeneous and nonhomogeneous building materials. The following relationships exist:

$$R = x/k = 1/C$$

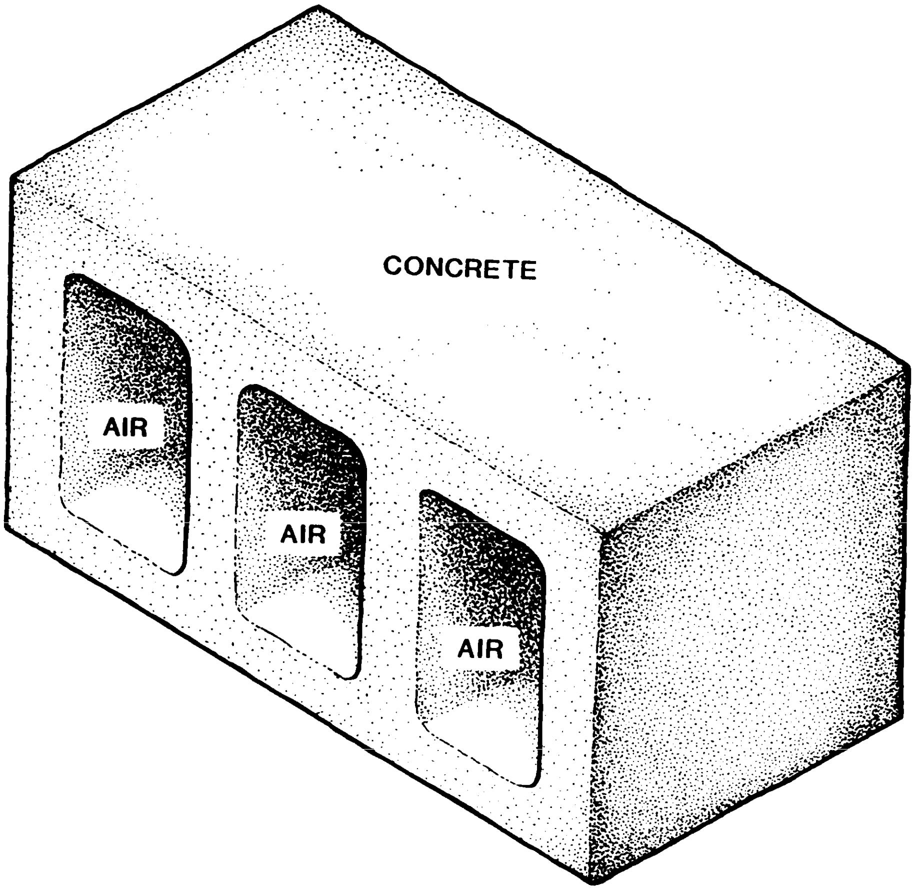


FIGURE 11. Three-oval-core concrete block.

where x = the thickness of the material. The resistance of a material structure is often called the R-value.

Table VI shows the thermal properties of some typical building materials.

5.4.2 Practical calculations.

5.4.2.1 The U-factor. The heat transfer properties of construction materials are used to determine the thermal characteristics of whole assemblies, such as walls, floors, and roofs. At this point, it is appropriate to introduce the effects of the surrounding air (fluid) on the heat transfer properties of a surface. The air film, which adheres to building surfaces for a number of physical reasons, adds to the insulating quality of the materials of which the walls are made. However, wind blowing against external walls reduces the insulating effect of the air film. For example, a 15 mph (24 kph) wind, which is the commonly accepted winter wind standard for U.S. design, will reduce the air film insulation by 75 percent. The summer wind standard is 7.5 mph (12 kph). Also, air films have different parameters on horizontal and vertical surfaces, respectively. See table VI. The heat transfer characteristic of a building assembly is called the U-factor or, sometimes, the U-coefficient. It is a measure of the heat transfer capability of the assembly, and is the sum of the characteristics of all of the materials present in the assembly, plus the air film effect. In practice, the U-factor is calculated by adding the resistances of all materials in the assembly and applying the following relationship:

$$U = 1/R_t$$

Where Rt = total resistance. Once the U-factor of an assembly is known, the next step is to calculate the transmission heat loss of the assembly, using the relationship:

$$\text{Heat loss of assembly in Btu/hr (BH)} = A \times U \times \Delta t$$

Where:

A = the area of the wall in square feet.
U = the U-factor of the assembly.
Δt = the difference in temperature of opposite assembly surfaces.

Figures 12 and 13 provide sample calculations of the transmission heat loss of two typical building walls. The examples shown on these figures are somewhat simplified. Other factors to be considered in design efforts include moisture content of materials, vapor barriers, and especially, solar effects. Note that the concrete block wall shown is constructed of materials with better insulating qualities than the framed wall and has approximately half the heat loss. The importance of insulation cannot be overemphasized. Table V shows the differences in the thermal resistance (R) of unit thickness of several insulating materials. The choice of material type and thickness is key to the design of an energy-efficient and cost-effective structure.

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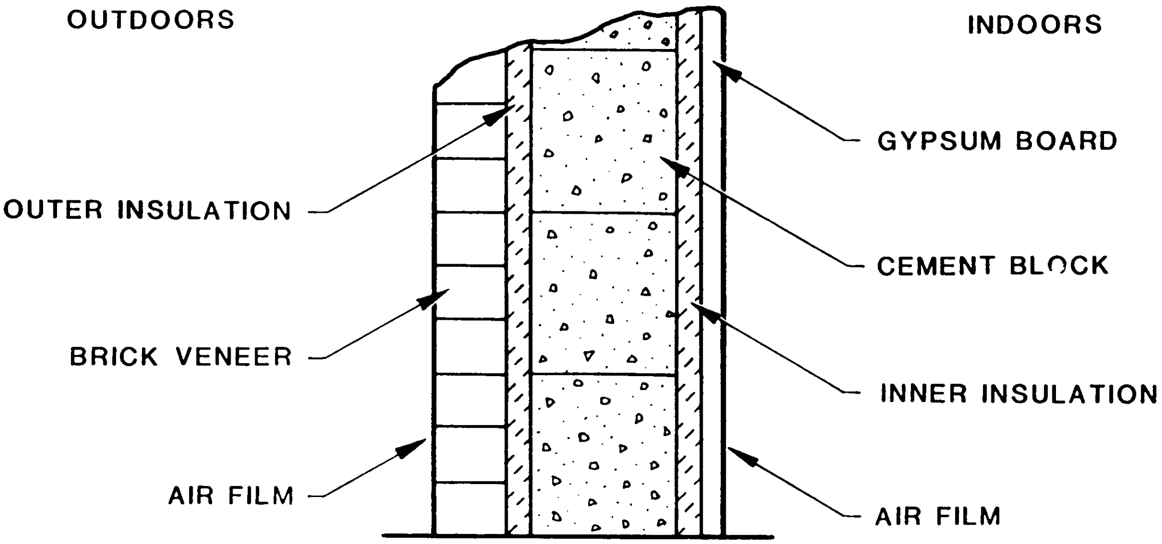
TABLE VI. Thermal characteristics of construction materials.

Description		Density lb/ft^3	Conductivity k	Conductance C	Resistance (R)	
					Per inch thickness 1/k	For thickness listed
Air films						
Walls, nonreflective						
Indoors				1.46		0.68
Outdoors, 15-mph wind				6.00		0.17
Outdoors, 7.5-mph wind				4.00		0.25
Ceilings, nonreflective						
Heat flow up (winter)				1.63		0.61
Heat flow down (summer)				1.08		0.92
Sloping, heat flow up				1.60		0.62
Sloping, heat flow down				1.32		0.76
Roofs--flat or sloping						
15-mph wind				6.00		0.17
7.5-mph wind				4.00		0.25
Building board						
Boards, panels, subflooring, sheathing, woodboard panel products						
Asbestos-cement board		120	4.0	...	0.25	
Asbestos-cement board	0.125 in.	120	...	33.00	...	0.03
Gypsum or plaster board	0.5 in.	50	...	2.22	...	0.45
Plywood (Douglas fir)		34	0.80	...	1.25	...
Plywood (Douglas fir)	0.5 in	34	...	1.60	...	0.62
Plywood or wood panels	0.75 in.	34	...	1.07	...	0.93
Vegetable fiber board						
Sheathing, regular density	0.5 in.	18	...	0.76	...	1.32
Sheathing, intermediate density	0.5 in.	22	...	0.82	...	1.22
Sound deadening board	0.5 in.	15	...	0.74	...	1.35
Tile and lay-in panels, plain or acoustic		18	0.40	...	2.50	
	0.5 in.	18	...	0.80	...	1.25

TABLE VI. Thermal characteristics of construction materials - Continued.

Description		Density lb/ft^3	Conductivity k	Conductance C	Resistance (R)	
					Per inch thickness 1/k	For thickness listed
Hardboard						
Medium density		50	0.73	...	1.37	
Particleboard						
Medium density		50	0.94	...	1.06	
Wood subfloor	0.75 in.		...	1.06	...	0.94
Building membrane						
Vapor-seal two layers of mopped 15-lb felt		...	...	8.35	...	0.12
Finish flooring materials						
Carpet and fibrous pad		...	...	0.48	...	2.08
Tile-asphalt, linoleum, vinyl, rubber, vinyl asbestos, ceramic		...	...	20.00	...	0.05
Wood, hardwood finish	0.75 in.			1.47		0.68
Insulating materials						
Blanket and batt						
Mineral fiber, fibrous form processed from rock, slag, or glass						
Approximately 2-2.75 in.		0.3-2.0	...	0.143	...	7
Approximately 8.5 in.		0.3-2.0		0.033		30
Board and slabs						
Cellular glass		8.5	0.38	...	2.63	
Expanded polystyrene extruded						
Smooth skin surface		2.2	0.20	...	5.00	

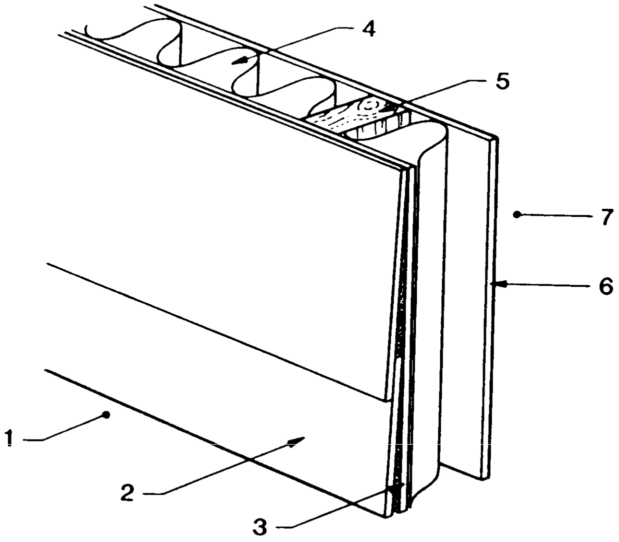


COMPONENT	R
1. OUTSIDE SURFACE AIR FILM (WIND @ 15 mph)	0.17
2. BRICK (4 IN)	0.44
3. OUTER INSULATION (2 IN)	14.49
4. CONCRETE BLOCK, 3-OVAL CORE (8 IN)	1.11
5. INNER INSULATION (1 IN)	7.19
6. GYPSUM WALLBOARD (0.5 IN)	0.45
7. INSIDE SURFACE AIR FILM	0.68
	R_T = 24.53
	U_T = 0.041

IF THE BRICK VENEERED BLOCK WALL WERE 8 FT HIGH AND TWELVE FT LONG, AND THE DIFFERENCE BETWEEN THE INDOOR AND OUTDOOR TEMPERATURES WAS 22°, THE HEAT TRANSMISSION OF THE WALL WOULD BE CALCULATED AS FOLLOWS:

$$\text{BTU/HR} = \text{AREA X } U_T \text{ X TEMP. DIFFERENCE}$$
$$=(8 \times 12) \text{ X } 0.041 \text{ X } 22=86.59$$

FIGURE 12. Transmission heat loss of block wall .



COMPONENT	R (INSULATION)	R (FRAMING)
1. OUTSIDE SURFACE AIR FILM (WIND = 15 mph)	0.17	0.17
2. WOOD LAPPED SIDING	0.81	0.81
3. SHEATHING (0.5 in)	1.32	1.32
4. R-11 FIBER BAT INSULATION	11.0	-
5. 2X4 WOOD STUD	-	4.38
6. GYPSUM WALLBOARD	0.45	0.45
7. INSIDE SURFACE AIR FILM	0.68	0.68
	Ri = 14.43 Ui = 0.069	Rf = 7.81 Uf = 0.128

FOR A FRAMED WALL (2X4) ON 16 in CENTERS), 85% OF THE AREA IS CONSIDERED TO CONTAIN THE INSULATION AND 15% TO CONTAIN THE STUDS.

$$U = (0.85X\ 0069) + (0.15 \times 0.128) = 0.078\ \text{Btu/hr/ft}^2/^{\circ}\text{F}$$

IF THE FRAMED WALL WERE 8 FT HIGH AND 12 FT LONG, AND THE DIFFERENCE BETWEEN THE INDOOR AND OUTDOOR TEMPERATURES WAS 22°, THE HEAT TRANSMISSION OF THE WALL WOULD BE CALCULATED AS FOLLOWS:

Btu/hr = AREA X U X TEMP DIFFERENCE
=(8 X 12) X 0.078 X 22= 164.74

FIGURE 13. Transmission heat loss of framed wall.

The use of insulating material on the inside, as well as on the outside, can be effective in reducing both heat transfer and noise. Special purpose insulating materials are also effective in controlling moisture.
heating plants and other support activities are in northside locations, for building efficiency purposes, the insulation of inner walls, adjacent to critical rooms, is recommended.

5.4.2.2 Heating load. The first step in designing the heating system for a building is to be determine the highest demand that the heating equipment will have to meet. This amount of heat is called the building heating load and is measured in Btu/hour. It is the amount of heat that is required to maintain the indoor temperature of a building within design parameters during the coldest anticipated weather conditions. To a great extent, mission equipment and operations will determine the indoor environment: temperature, humidity, and air cleanliness. Geographical location, personnel support features, security considerations, energy conservation, and environmental protection influence the achievement of these design features. The size and type of heating and cooling plants will depend directly on heat losses and gains. In order to estimate the heating load of a building, the potential heat losses of every room and space must be determined. This section presents the information necessary to understand the heat losses which establish the heating load and influence the selection of HVAC equipment. While heat gains can temporarily reduce the amount of heat that must be provided by a heating system, that system must still have the capability of meeting the total heat requirement when those heat gains are not present. In the interest of energy conservation, it is important that the effective use of substantial heat gains be considered, possibly through heat recovery or cogeneration.

5.4.2.2.1 Winter design conditions. The selection of heating systems capable of maintaining the indoor design temperatures must tale into account the outdoor winter design conditions, including winds. The 99-percent DBT and MCWBT outdoor winter design conditions should be used in calculations for critical areas, and the 97.5-percent DBT and MCWBT should be used for technical areas. Electronic equipment manufacturers normally recommend specific climatic conditions for optimum performance. The following basic indoor design conditions are recommended for DoD communications and data processing facilities:

a. Computer rooms. A temperature of 72+2 °F (22±1 °C), a relative humidity of 45+5 percent, and an air filter efficiency (spot dust) of 60-65 percent are recommended (see 5.6.4). Spaces that house ancillary devices and materials such as magnetic tape and storage disks, call for similar conditions, although tolerances may not be as critical.

b. Transmitter buildings. A temperature up to 90 °F (32 °C) for large heat-producing transmitters is recommended. This temperature is high enough to preclude damage to equipment from moisture, even in locations of high humidity, using only ventilation. In locations where air contaminants (dust, polution, salt spray, sand, etc.) require the use of environmental control systems other than simple ventilation, a temperature of 90 °F (32 °C) and relative humidity of 50±10 percent are recommended, provided the humidity range can be maintained without significant need for humidification. (Latent heat is required for humidification.)

c. Electronic equipment buildings/rooms. These areas include space for receivers, telephone central office equipment, and similar electronic devices. A temperature of 75+5 °F (22+2 °C), relative humidity of 40-60 percent, and an air filter efficiency (spot dust) of 60-65 percent are recommended.

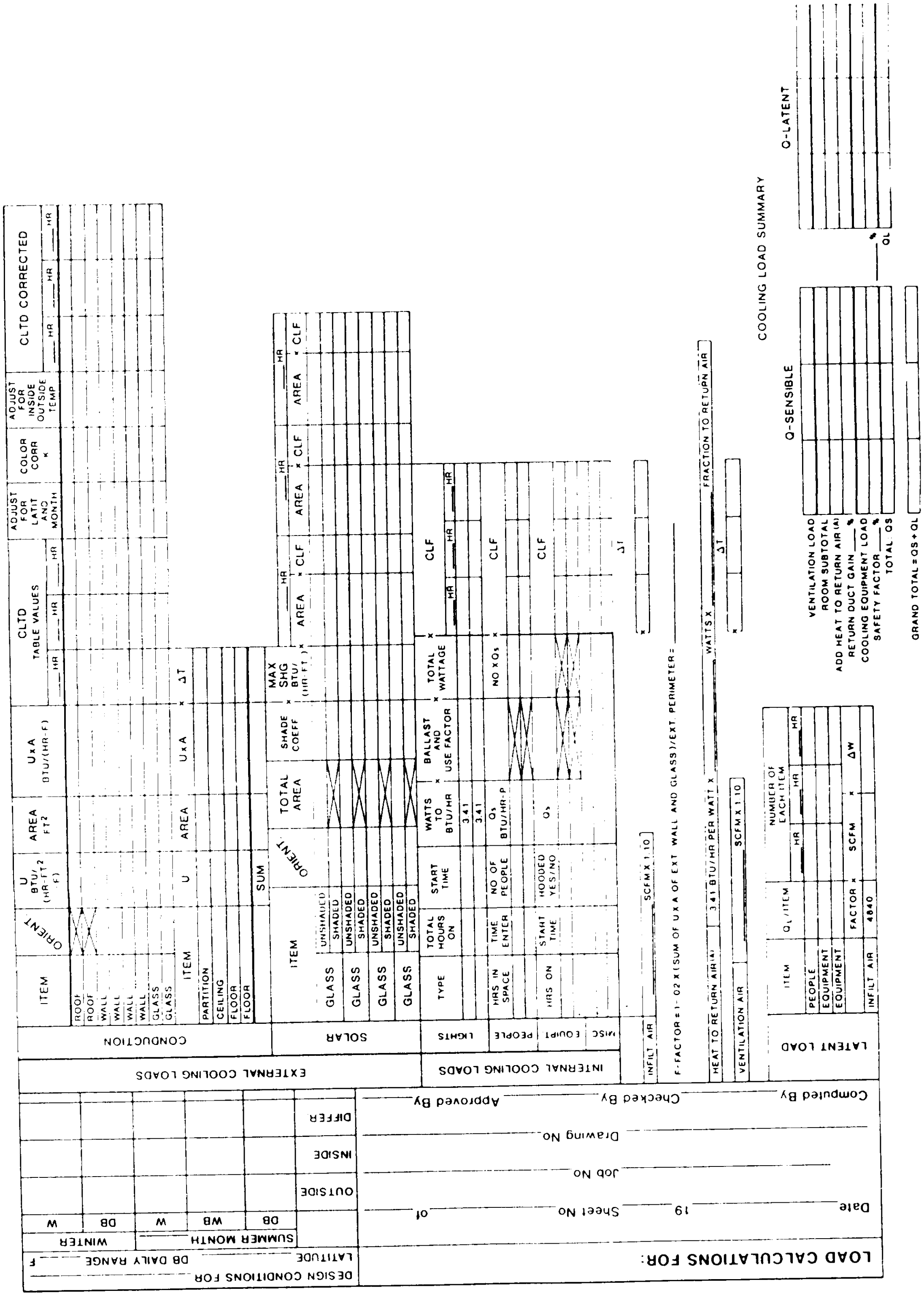
d. Administrative and personnel areas. A temperature range of 68 to 80 °F (20 to 27 °c), with appropriate range of relative humidity of 30 to 70 percent, is recommended. See figure 5 and paragraph 5.2.9.

e. 0ther technical areas. These include power production, UPS, and battery rooms. see volume II.

The indoor conditions listed above are only a guide. The recommendations of the manufacturers must always be considered. Because electronic devices normally generate heat, it is recommended by ASHRAE that indoor design temperatures be set at the low end of the tolerance scale to allow for better dissipation of the generated heat. Humidity level control is addressed in a separate section. However, heating and cooling systems supporting critical and most technical areas must incorporate both humidifying and dehumidifying capabilities. Excessive humidity in a communications/data processing facility can adversely affect card and paper feeding, and produce damaging condensation. Humidity that is too low can increase dust and harmful static discharge. Maintaining precise temperature control and energy conservation mandates that special construction features, such as air leak (infiltration) protection, high quality insulation, and double- or triple-glazed windows, be considered in the design. These subjects are addressed in 5.4.

5.4.2.2.2 Heat losses. Building heat losses occur through infiltration and transmission. These subjects were introduced in 5.2.10.4. The various heat losses are calculated and summarized using worksheets, such as the one shown in figure 14.

a. There are two ways to estimate infiltration heat losses: the air change method and the crack method. In the air change method, the number of times per hour that the room air is replaced by outside air is approximated. The amount of energy required to heat (sensible and latent) the colder infiltrating air is then calculated in Btu/hr. The number of air changes per hour due to infiltration will range between zero and three for most structures. Traffic in and out of a space and the number of doors and windows greatly influence the amount of infiltration. The air change method is generally considered to be inaccurate, unless performed by very experienced personnel, and the crack method is preferred. As the name implies, the crack method is concerned directly with openings in the building envelope that allow outside air to infiltrate. The heating designer measures the length of joints or “cracks” around doors, windows, and other openings. Those dimensions are then related to tables of infiltration data, such as shown in table VII, to estimate the amount of leakage (typically in^2 per ft or ft^2) for these components. The indoor/outdoor temperature differential, building stack effect, wind velocity, and a coefficient for wind shielding



LOAD CALCULATIONS FOR:

Date ______ 19 ___ Sheet No ______ of ______

Job No ______

Drawing No ______

Computed By ______ Checked By ______ Approved By ______

DESIGN CONDITIONS FOR ______

LATITUDE ______ DB DAILY RANGE ______ F

	SUMMER MONTH			WINTER	
	DB	WB	W	DB	W
OUTSIDE					
INSIDE					
DIFFER					

EXTERNAL COOLING LOADS

CONDUCTION

ITEM	ORIENT	U BTU/(HR·FT² F)	AREA FT²	U×A BTU/(HR·F)	CLTD TABLE VALUES HR	HR	HR	ADJUST FOR LATIT AND MONTH	COLOR CORR ×	ADJUST FOR INSIDE OUTSIDE TEMP	CLTD CORRECTED HR	HR	HR
ROOF													
ROOF													
WALL													
WALL													
WALL													
WALL													
GLASS													
GLASS													

ITEM	U	AREA	U×A	× ΔT
PARTITION				
CEILING				
FLOOR				
FLOOR				
SUM				

SOLAR

ITEM		ORIENT	TOTAL AREA	SHADE COEFF	× MAX SHG BTU/(HR·FT²) ×	AREA × CLF HR	AREA × CLF HR	AREA × CLF HR
GLASS	UNSHADED							
	SHADED							
GLASS	UNSHADED							
	SHADED							
GLASS	UNSHADED							
	SHADED							
GLASS	UNSHADED							
	SHADED							

INTERNAL COOLING LOADS

LIGHTS	TYPE	TOTAL HOURS ON	START TIME	WATTS TO BTU/HR ×	TOTAL AREA	BALLAST AND USE FACTOR ×	TOTAL WATTAGE ×	CLF HR HR HR
				3.41				
				3.41				
PEOPLE	HRS IN SPACE	TIME ENTER	NO OF PEOPLE	Qs BTU/HR-P			NO × Qs ×	CLF
EQUIPT	HRS ON	START TIME	HOODED YES/NO	Qs				CLF
MISC								ΔT

INFILT AIR ______ SCFM × 1.10 ______ × ΔT ______

F-FACTOR = 1 - .02 × (SUM OF U × A OF EXT WALL AND GLASS)/EXT PERIMETER = ______

HEAT TO RETURN AIR(A) ______ 3.41 BTU/HR PER WATT × ______ WATTS × ______ FRACTION TO RETURN AIR ______

VENTILATION AIR ______ SCFM × 1.10 ______ × ΔT ______

LATENT LOAD

ITEM	Q_L/ITEM	NUMBER OF EACH ITEM	HR	HR	HR
PEOPLE					
EQUIPMENT					
EQUIPMENT					
INFILT AIR	FACTOR × 4840	SCFM ×	ΔW		

COOLING LOAD SUMMARY

	Q-SENSIBLE			Q-LATENT		
VENTILATION LOAD						
ROOM SUBTOTAL						
ADD HEAT TO RETURN AIR (A)						
RETURN DUCT GAIN ___ %						
COOLING EQUIPMENT LOAD						
SAFETY FACTOR ___ %						
TOTAL QS				QL		
GRAND TOTAL = QS + QL						

FIGURE 14. Heat/cooling load worksheet.

are combined with the component leakage values to compute the building infiltration estimate. Both sensible and latent heat are included in the calculation of the component of the heating load attributed to infiltration. Electronic equipment rooms of communications/data processing installations have a reduced potential for infiltration, because they are usually provided with positive air pressure to minimize incoming dust and other contaminants of unconditioned air. Also, doors and windows are generally kept to a minimum for environmental control and security reasons.

b. Transmission losses can occur through all surface areas of a room, walls, floor, and ceiling, The amount of heat lost through these surfaces relates to the types of materials of which they are made and the temperature differentials in the adjacent rooms or spaces. The calculation of transmission heat losses through above grade (ground level) walls, ceiling, and floors is similar to the examples of figures 12 and 13.

The basic formula is:

$$BH = A \times U \times t$$

Where t represents the difference between the indoor and outdoor winter design temperatures for outside walls and floors, or the temperature differential with other adjacent indoor spaces. Calculations for below-grade floors and outside walls employ the basic formula, modified with information such as that given in table VIII and figure 15 for values of U and t, respectively. The contour lines on the figure outline areas in which the average winter ground temperatures are approximately equal. The temperature values shown are subtracted from the outdoor design temperatures used in calculations. Lowering the temperature used in calculations compensates for the effects of colder ground temperatures in the more northerly areas.

For floors at round level, typically concrete slabs, the majority of heat loss is through the perimeter areas. The amount of heat loss in Btu per hour is estimated by using the special formula:

$$BH = F \times P \times t$$

Where F is a coefficient of heat loss for an on-grade slab floor determined by the type of connecting outer wall, insulation, and local climate, as show in table IX, and P is perimeter of the floor.

Estimating heat losses for attic and crawl spaces is somewhat more complicated than other building areas because they can have a variety of surfaces that require different methods of calculation. For example, a crawl space might have a dirt floor and provide a path for the ductwork or piping of heating, cooling, or ventilating systems. The special features of these spaces must be carefully analyzed and figured into the heat loss calculation by application of the most appropriate formulas. Table X lists the heating load calculation formulas used by ASHRAE. Figure 14 is an example of a worksheet used to summarize heat losses.

Table VII. Examples of component air leakage data.

Component Leakage: Sill Foundation -- Wall

Component	Best Estimate	Max[a]	Min[a]	Unit
Sill (caulked) per ft of perimeter	0.04	0.06	0.02	in^2/ft
Sill (not caulked) per ft of perimeter	0.19	0.19	0.05	in^2/ft

Component Leakage: Joints Between Ceiling and Walls

Component	Best Estimate	Max[a]	Min[a]	Unit
Joints per ft of wall (only if not taped or plastered and no vapor barrier)	0.07	0.12	0.02	in^2/ft

Component Leakage: Windows

Component	Best Estimate	Max[a]	Min[a]	Unit
Casement (Weather stripped per ft^2 window)	0.011	0.017	0.006	in^2/ft^2
Same (not weather stripped)	0.023	0.034	0.011	in^2/ft^2
Double hung (Weather stripped per ft^2 window)	0.043	0.063	0.023	in^2/ft^2
Same (not weather stripped)	0.086	0.126	0.046	in^2/ft^2

TABLE VII. Examples of component air leakage data. (continued)

Component Leakage: Doors				
Component	Best Estimate	Max.[a]	Min.[a]	Unit
Double door (Weather stripped per ft^2 door)	0.114	0.215	0.043	in^2/ft^2
Same (not weather stripped)	0.16	0.32	0.1	in^2/ft^2

A Maximum and minimum are not in the literature. The given values of max. and min. are used in the calculations.

Table VIII. Heat loss coefficient (U) for below-grade floors and walls.

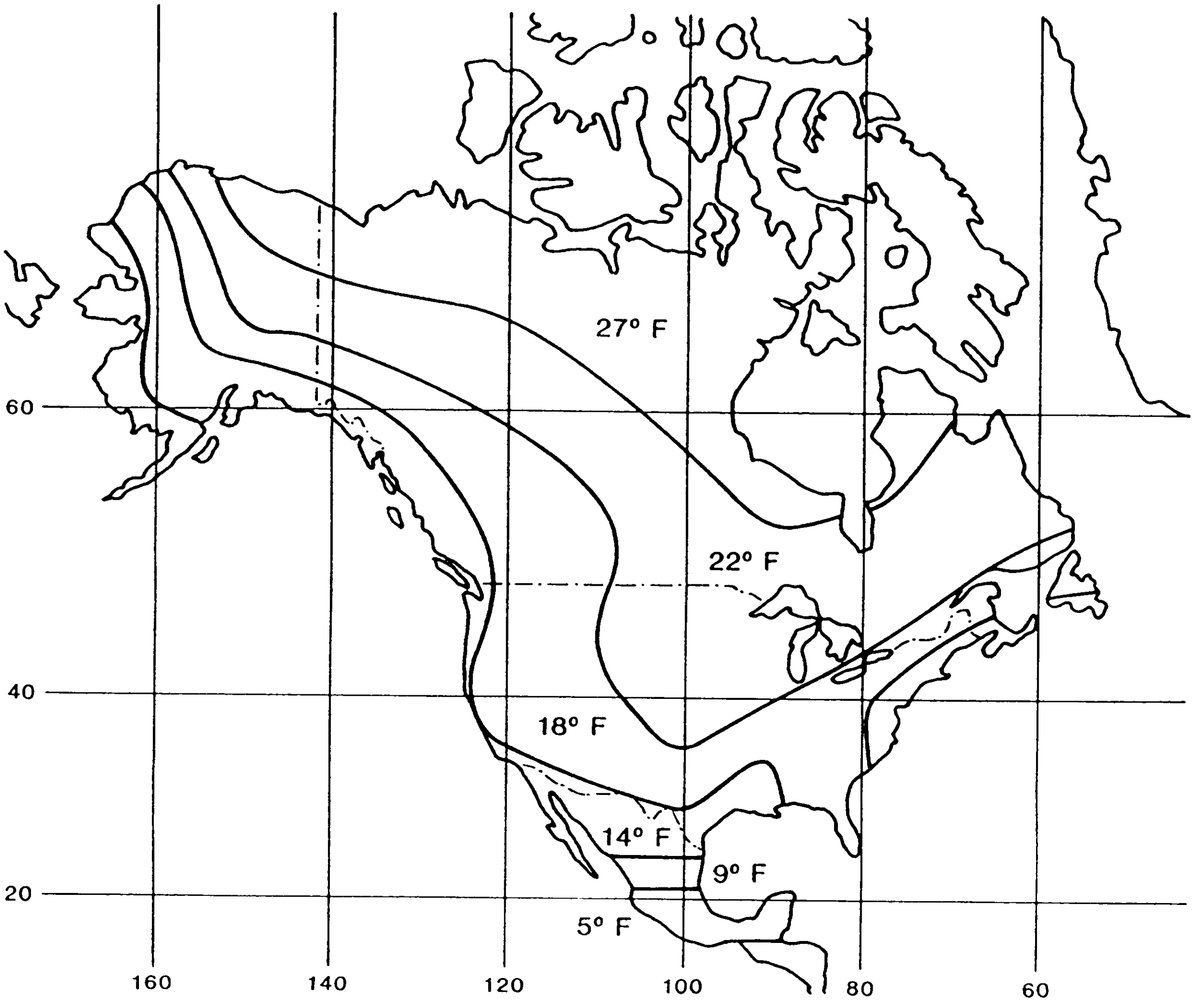
A. Heat loss through basement floors
(Btu/h) ft^2 X °F

Depth of foundation wall below grade (ft.)	Shortest width of house (ft.)			
	20	24	28	32
5	0.032	0.029	0.026	0.023
6	0.030	0.027	0.025	0.022
7	0.029	0.026	0.023	0.021

B. Heat loss below grade in basement walls

Depth ft.	Path length through soil ft.)	Heat loss, (Btu/h)ft. X °F							
		uninsulated		R=4.17		R=8.34		R=12.5	
0-1	0.68	0.410		0.152		0.093		0.067	
1-2	2.27	0.222	0.632	0.116	0.268	0.079	0.172	0.059	0.126
2-3	3.88	0.155	0.787	0.094	0.362	0.068	0.240	0.053	0.179
3-4	5.52	0.119	0.906	0.079	0.441	0.060	0.300	0.048	0.227
4-5	7.05	0.096	1.002	0.069	0.510	0.053	0.353	0.044	0.271
5-6	8.65	0.079	1.081	0.060	0.570	0.048	0.401	0.040	0.311
6-7	l0.28	0.069	1.150	0.054	0.624	0.044	0.445	0.037	0.348

NOTE: For floors, U is selected by depth below grade and the shorter rectangular dimension. For walls, U is determined by adding values on a per foot of depth basis, for the respective value of insulation.



NOTE:

THE CONTOUR LINES ON THE FIGURE OUTLINE AREAS IN WHICH THE AVERAGE WINTER GROUND TEMPERATURE VALUES SHOWN ARE SUBTRACTED FROM THE OUTDOOR DESIGN TEMPERATURES USED IN CALCULATIONS. LOWERING THE TEMPERATURE USED IN CALCULATIONS COMPENSATES FOR THE EFFECTS OF COLDER TEMPERATURES IN THE MORE NORTHERLY AREAS.

FIGURE 15. Temperature lines of constant amplitude.

TABLE IX. Heat loss coefficient (F) for on-grade slab floors.

Construction	Insulated	Heating Degree Days (65 °F Base)		
		2950	5350	7433
8-in. block wall, brick facing	Uninsulated R = 5.4 from edge to footer	0.62 0.48	0.68 0.50	0.72 0.56
4-in. block wall, brick facing	Uninsulated R = 5.4 from edge to footer	0.80 0.47	0.84 0.49	0.93 0.54
Metal stud wall, stucco	Uninsulated R = 5.4 from edge to footer	1.15 0.51	1.20 0.53	1.34 0.58
Poured concrete wall with duct near perimeter[a]	Uninsulated R = 5.4 from edge to footer, 3 ft under floor	1.84 0.64	2.12 0.72	2.73 0.90

[a] Weighted average temperature of the heating duct was assumed at 110 °F during the heating season (outdoor air temperature less than 65 °F).

F = Heat loss, Btu/h/°F per ft. of perimeter

TABLE X. Heating load calculations formulas.

Heating Load	Equation	Reference*, Table, Description
Roofs, walls, glass	$q = U \times A \times TD$	Tables 3.1-3.5 and A-3.1 Areas calculated from plans or obtained by survey temperature difference between inside dry buld and design outside dry bulb. Table 2.1
Floors over exterior space	$q = U \times A \times TD$	Same as above.
Floors on or below grade	$q = U \times A \times ID$ and or $q = U \times F \times P$	temperature difference between inside design dry bulb ground temperature. Table 7.1 and Fig. 7.2 Table 7.9, perimeter heat loss factor Perimeter of slab measured in feet
Walls below grade	$q = U \times A \times TD$	Table /.4 Table 7.1 and Fig. 7.2 Area calculated from plans or survey
Ventilatlon & infiltration		Ventilation load is imposed where the ventilation air is conditioned. It does not necessarily become part of the space load. Constants are defined on page A-6.2 by Equations (A-6.1-A-6.5). Ventilation and Infiltration Air, Standard CFM, Chapter 5
Sensible	$q_s = 1.08 \times CFM \times t$	Inside-Outside Air Temperature Difference, °F, Table 2.1
Latent	$q_l = 4840 \times CFM \times W$	Inside-Outside Air Humidity Ratio Difference, lb H_2O/lb Dry Air, Tables 2.1 and
Total	$q = 4.5 \times CFM \times h$	Inside-Outside Air Enthalpy Difference, Btu/lb of Dry Air, Psychometric Chart
Balance point temperature	$t = t_i - \frac{\text{Heat Gain}}{\text{Heat Loss}}$ Factor	Approximate balance point temperature, outside design inside dry bulb temperature Sum of heat gains Internal heat gains or internal gains plus solar heat gain calculated according to procedure of cooling load Heat loss factor = Unoccupied design heat load divided by design temperature difference

*References are in Cooling and Heating Load Calculation Manual (GRP 158).

5.4.2.3 Cooling load. The building cooling load is the amount of cooling, or heat removal in Btu/hr or watts, required to maintain the design conditions of the rooms and spaces of that building. The cooling load component of each room or space consists of two parts - the sensible cooling load and the latent cooling load. Sources of the cooling load, which are listed in 5.2.10.4.2, are divided into two groups - internal and enternal. Internal sources include those which are generated within the room or space, such as personnel, equipment, and lighting. All others are referred to as external sources. Estimated cooling loads should include a growth potential. It is important to recognize that most of the heat produced in electronic facilities is sensible heat. The ratio of sensible to total heat can approach unity. Cooling coil performance must match this ratio, or inefficient control of space temperatures and humidity can result. Cooling coils for comfort applications are designed to handle greater amounts of latent heat and are not suited for cooling of most electronic installations (see 5.5.3.lb). The load component of the individual rooms and spaces varies with the time of day and month of the year. The extremes of these demands also occur at different times. Solar radiation is a great source of heat in many geographical areas. As previously indicated, the control of the effects of solar radiation must be considered in facility design, using site survey data.

a. The composition of the total cooling load of DoD electronic facilities differs from most other installations because of the large and relatively constant amount of sensible heat produced by mission equipment. In newer facilities, lighting can become the most significant component of the cooling load. The effects of solar radiation and heat transmission through building surfaces may be a small percentage of the total load. Accordingly, the expenditure of funds for special construction features, such as greatly increased wall insulation to reduce the heating effects of solar radiation, may not be justified when reviewed in terms of life cycle costs. While heat gains occur through transmission and infiltration, as do heat losses, their effects may not be immediate. Some of the radiant heat introduced into a room is absorbed by the room surfaces and objects within the room and does not immediately affect room air temperature. Warming of the room air by convection takes place after the surfaces and objects become warmer than the air surrounding them. Accordingly, instantaneous heat gains and cooling loads are not necessarily the same. Failure to take into account the transient characteristics of cooling loads can easily result in the selection of equipment that is actually two large for the job. This deficiency in the design stage causes unnecessary increases in both initial and operating costs.

b. In its continuing efforts to refine methods for calculating cooling loads, ASHRAE has developed procedures which take into account the differences between instantaneous heat gains and cooling loads due to transient effects. Concepts called “time averaging and “transfer functions” make adjustments based on recent historical data on heat transfer within the space and the effects of space size, geometry, and type of construction. Computer programs are available to provide assistance wit these calculations. Details of these procedures are beyond the scope of this text. ASHRAE has also developed tables of data for use in the manual calculation of cooling loads. These data, called

"Cooling Load Temperature Difference" (CLTD) and "Cooling Load Factor" (CLF), provide for the time delay attributed to heat storage in room surfaces. Sol-air temperature is an adjusted outdoor temperature that takes into account the effects of solar radiation. Table XI shows examples of information that is available from ASHRAE cooling load calculation data. An explanation of terms is included. The load calculation worksheet shown in figure 14 includes spaces for entering CLTD and CLF data. Further information can be found in the ASHRAE handbooks and the cooling and heating load calculation manual. ASHRAE calculation methods should be used for DoD facilities, taking into account the weather design values outlined in this handbook. Informal information indicates that ASHRAE will recommend the use of transfer functions as the best calculation method in its next handbook.

5.4.2.3.1 Summer design conditions. The following outdoor summer design conditions from military service engineering weather data manuals should be applied when engineering the environmental control systems of DoD communications and data processing facilities.

a. Critical areas requiring close tolerance control of temperature and humidity should use l-percent dry-bulb and l-percent wet-bulb temperatures.

TABLE XI. Example of ASHRAE cooling load calculation data.

Cooling Load Temperature Differences
for Calculating Cooling Load from Sunlit Walls

	Solar Time[1], h 400	08OO	1200	1600	2000	2400	Hr of Max. CLTD	Min. CLTD	Max. CLTD	Difference CLTD
North latitude										
Wall facing	Group A walls[2]									
N	13	12	10	10	12	14	2	10	14	4
NE	18	15	15	18	19	20	22	15	20	5
E	23	19	19	23	25	25	22	18	25	7
SE	22	19	18	21	24	24	22	18	24	6
S	19	16	14	15	19	20	23	14	20	6
SW	24	21	18	17	22	25	24	17	25	8
W	26	23	19	18	22	26	1	18	27	9
NW	20	18	15	14	17	21	1	14	21	7

Cooling Load f-actors for Glass without Interior Shading,
North Latitudes

Fenestration facing	Room construction	Solar time, h 4	8	12	16	20	24
	L	0.09	0.48	0 /6	0.79	O 48	0.20
N	M	0.16	0.46	0.70	0.74	0.50	0.27
(Shaded)	H	0.20	0.49	0.69	0.70	0.46	0.28
	L	0.03	0.47	0.39	0.33	0.16	0.07
NNE	M	0.06	0.42	0.36	0.33	0.18	0.10
	H	0.09	0.42	0.34	0.31	0.18	0.12

L = light construction, M = medium construction, and H = heavy construction

[1] Solar time is an adjusted time which relates to the apparent motion of the sun, due to the angle at which it is being viewed.

[2] Group A refers to a particular type of wall construction.

b. Any areas that can tolerate broader control of temperature and humidity (including technical areas) should use 2.5-percent dry-bulb and mean coincident wet-bulb temperatures (MCWBT).

c. Other areas will depend upon the activity being performed and the comfort conditions required by personnel occupancy. Indoor design conditions recommended for DoD communications and data processing facilities are given in 5.4.2.2.1.

5.4.2.3.2 Heat gains. When the temperature outside an environmentally controlled space is higher than the inside design temperature, heat enters the space through transmission and infiltration. These sensible heat gains develop and are measured much the same way as heat losses, which occur when the outside temperature is lower than the inside design temperature. Just as with heat losses, the types of construction, materials used, winds, stack effect, doors, windows, and ventilation systems influence the rate of heat gain. Table XII shows some of the the cooling load calculation formulas developed by ASHRAE. The latent heat load must also be determined when infiltrating air introduces unwanted humidity to the controlled air space. Cooling equipment is designed and rated according to its ability to handle both sensible and latent cooling loads. The following formulas provide estimates of heat loads associated with air change:

Sensible air change: Btu/hr = cfm x l.08 x Δ t
Latent air change: BTu/hr = cfm x 4840 x humidity ratio (W) difference.
Total load air change: cfm x 4.5 x enthalpy (h) difference

Rooms containing humidity-sensitive electronic devices, such as computers, should be provided with vapor retarders to minimize the gain or loss of moisture. Electronic facilities usually operate with lower summer humidities and higher winter humidities than do comfort applications. Vapor retarders are discussed later in this volume in sections concerning humidity control and the uses of insulation.

a. Internal heat gains from electronic equipment, commonly found in communications and data processing facilities, are almost exclusively in the form of sensible heat. Information concerning the rate of heat generated by equipment is normally provided by the manufacturer. Heat gains from lighting can be a significant part of the cooling load of communications and data processing installations, where the availability of natural light is minimized by the limited use of fenestration. Note that the cooling load calculation formulas of table XII and the worksheet of figure 14 include an allowance for lights. If electronic equipment rooms are properly designed and constructed with moisture retarders to minimize the entry of unwanted humidity from external sources, the major internal source of moisture is personnel and the latent heat portion of ventilation required for them. Heat and moisture gains attributed to personnel occupying a space are, of course, dependent on the type of activity in which the occupants are engaged. The type of clothing being worn and the environmental conditions within the room are also contributing factors.

Table XII. Cooling load calculations formulas.

LOAD SOURCE	EQUATION	REFERENCE*, TABLE, DESCRIPTION
External Roof	$q = U \times A \times CLTD$	Design heat transmission coefficients--Tables 3.1-3.5, A-3.1 and A-3.2 Areas calculated from Architectural Plan Cooling load temperature difference, base conditions for Roofs--Table 3.8 and Notes Note 2--Correction for color of exterior surface Note 2--Correction for outside dry-bulb temperature and daily range--Table 3.13 Note 2--Correction for inside dry-bulb temperature--Table 3.13 Note 2--Application for latitude and month--Table 3.12
Walls	$q = U \times A \times CLTD$	Design heat transmission coefficients--Tables 3.1-3.4, A-3.1 and A-3.2 Area calculated from Architectural Plan Wall construction group description--Table 3.9 Cooling load temperature difference at base conditions for wall group--Table 3.10 and Notes Note 2--correction for color of exterior surface Note 2--Correction for outside dry-bulb temperature and daily range--Table 3.13 Note 2--Correction for inside dry-bulb temperature--Table 3.13 Note 2--Application for latitude and month--Table 3.12
Solar	$q = A \times SC \times SHGF \times CLF$	Area--net glass area calculated from plans Shading coefficients for combination of type of glass and type of shading--Tables 3.17-3.22 Maximum solar heat gain factor for specific orientation of surface, latitude and month--Table 3.25 for no external shading Externally shaded Location less than 24° N lat--Table 3.26 Location at or more than 24° N. lat--Table 3.25, north orientation Cooling load factor with no interior shading--Table 3.27 Cooling load factor if interior shading is used--Table 3.28 For glass areas shaded externally--use north orientation with either Table 3.27 or 3.28

* References in ASHRAE Cooling and Heating Load Calculation Manual (GRP 158).

b. The sensible and latent heat gains produced by the occupants of an environmentally controlled space are shown in table XIII. The data contained in this table accounts for a variety of activity levels and includes adjustments for men, women, and children. The human body produces heat through the process of metabolism, the oxidation of food. Metabolism is measured by the rate of oxygen consumption. The rate of metabolism, of course, depends upon the amount of work the body is performing when measurements are taken. Heat and moisture are transferred between individuals and their environment at the skin surface through blood flow and sweating.

5.5 Environmental equipment and systems. As previously discussed, specific environmental conditions must be established for every room and space within the building. The selection of HVAC equipment and systems is based upon this information. These environmental conditions are determined by the activity or functions performed in the rooms and spaces, plus considerations of personal comfort.

a. Critical areas supporting the more environmentally sensitive activities, such as computer operations, clean-room functions, and other electronic activities will have very stringent requirements for the control of temperature, humidity, air cleanliness, and air quality. Equipment should operate within the comfort range of the operators. These critical areas are usually provided with backup dedicated environmental control systems. Technical areas will also have stringent requirements, but generally with broader tolerances. Other areas used for activities, such as storage or utility support, will often be designed to have relatively high or low temperatures and humidity levels, and may actually require little or no environmental control. Backup systems must, as a minimum, be able to provide the indoor design conditions for critical and technical areas. Recent efforts to conserve energy have encouraged the maintenance of lower winter temperatures and higher summer temperatures. In those areas where there is no sensitive equipment and personnel activity is limited, extensive environmental control is not needed.

b. Personal comfort is a very subjective matter, influenced by many more factors than merely temperature and humidity. These factors include noise, vibration, dust, drafts, odors, clothing, lighting, radiant heat effects, levels of physical activity, and even the proximity of other personnel. The environmental conditions required for electronic equipment are generally within the comfort range of most personnel, but there can be exceptions which must be given special consideration.

c. There is *no* standard type of environmental control system for DoD communications and data processing facilities. The advantages and disadvantages of using the various types of HVAC devices in these DoD facilities are included in the text. HVAC equipment and system selection will be based on the following factors, most of which should be identified by the site survey:

Table XIII. Heat produced by people.

Degree of Activity	Typical Application	ADULT MALE Total qs/person + ql/person		ADJUSTED GROUP^b Total q_s/person + q_l/person		ADJUSTED GROUP^b Sensible q_s/person		ADJUSTED GROUP^b Latent q_l/person	
		Watts	Btu/hr	Watts	Btu/hr	Watts	Btu/hr	Watts	Btu/hr
Seated at rest	Theater, movie	115	400	100	350	60	210	40	140
Seated, very light work writing	Offices, hotels, apts	140	480	120	420	65	230	55	190
Seated, eating	Restaurant^c	150	520	170	580^c	75	255	95	325
Seated, light work, typing	Offices, hotels, apts	185	640	150	510	75	255	75	255
Standing, light work or walking slowly	Retail store, bank	235	800	185	640	90	315	95	325
Light bench work	Factory	255	880	230	780	100	345	130	435
Walking, 3 mph, light machine work	Factory	305	1040	305	1040	100	345	205	695
Bowling^d	Bowling Alley	350	1200	280	960	100	345	180	615
Moderate dancing	Dance Hall	400	1360	375	1280	120	405	255	875
Heavy work, heavy machine work, lifting	Factory	470	1600	470	1600	165	565	300	1035
Heavy work, athletics	Gymnasium	585	2000	525	1800	185	635	340	1165

[a] NOTE: Tabulated values are based on 78°F room dry-bulb temperature. For 80°F room dry-bulb, the total heat remains the same sensible heat value should be decreased by approximately 8% and the latent heat values increased accordingly.

[b] Adjusted total heat gain is based on normal percentage of men, women, and children for the application listed, with the postulate gain from an adult female is 85% of that for an adult male, and that the gain from a child is 75% of that for an adult male.

[c] Adjusted total heat value for eating in a restaurant, includes 60 Btu/hr for food per individual (30 Btu sensible and 30 Btu/hr).

[d] For bowling, figure one person per alley actually bowling, and all others as sitting (400 Btu/hr) or standing and walking slowly

(1) Environmental conditions required by mission equipment.

(2) Total environmental control requirements of the facility.

(3) Local climatic conditions.

(4) Local availability of environmental systems.

(5) Local availability of utilities, both DoD and commercial.

(6) Local availability of maintenance and supply support.

(7) Estimated life cycle costs of HVAC systems.

(8) Operational compatibility among HVAC systems and with mission equipment. HVAC systems must not interfere with the reliable operation of mission equipment or each other. The protection of power sensitive mission equipment is of major concern.

d. Environmental control systems can be categorized into two general types - central plant and unitary. A central plant refers to a centralized installation that services all or most of the rooms in a building, or two or more buildings. A unitary device services one specific room or space. A residential room or window air conditioner is an example of a unitary system. Environmental systems which combine both heating and cooling functions are classified by the medium they use (air or water) for the convection heat transfer processes. The terms “all-air”, "all-water”, and “air-and-water” systems are in common usage in the HVAC industry.

5.5.1 Heating equipment. The selection of heating systems is based upon the total estimatedheating load of the facility. At locations that contain critical or technical areas, primary and secondary (back-up) heating systems will be installed. The primary system should have the capacity to meet the entire facility heating load. The secondary system should have the capacity to meet the heating requirements of the critical and technical areas. Central plant heating Systems are often used, for reasons of economy and efficiency, in large buildings. The joint use of distribution networks for heating and cooling, such as ductwork, is common. In ADP and other electronic facilities, much of the task of maintaining a design temperature range is accomplished by the cooling function of an environmental control system because the equipment produces significant amounts of heat within a closed space. Heating systems fall into five general groups:

a. Forced-air systems.

b. Hot water systems.

c. Steam systems.

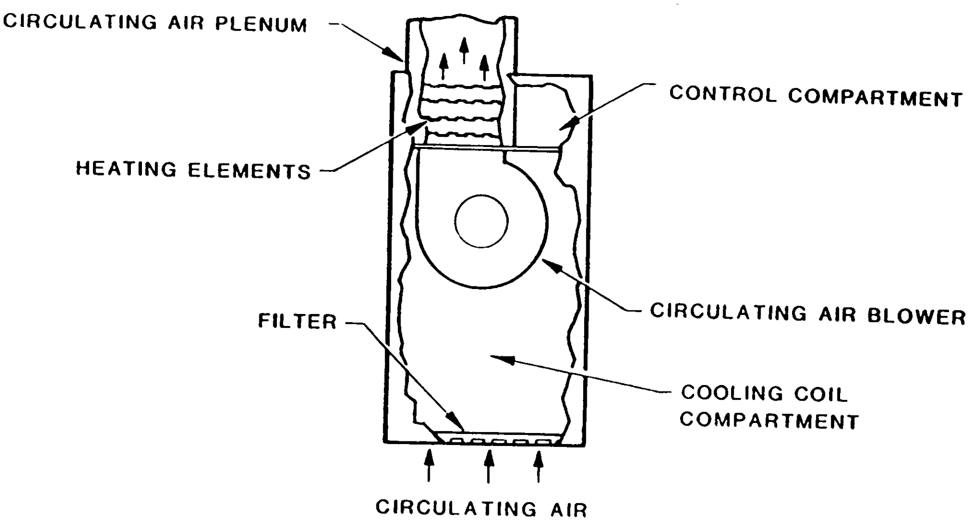
d. Radiant panel systems.

e. Supplemental heating systems.

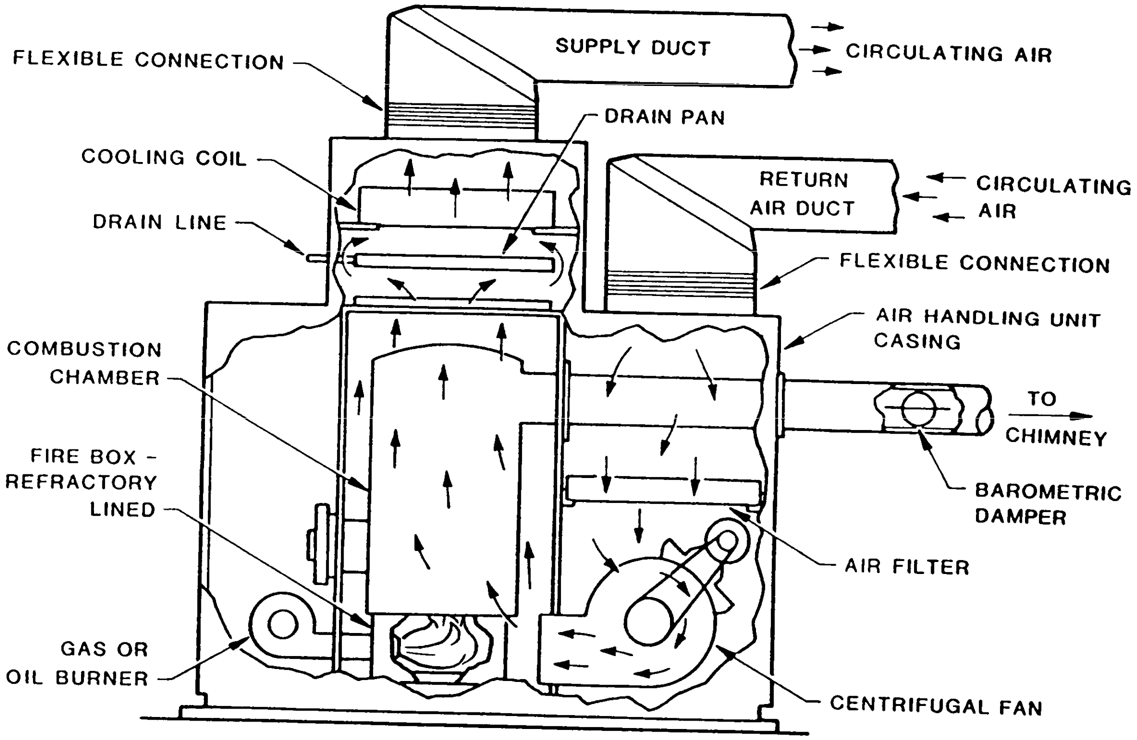
5.5.1.1 Forced-air systems. Forced air systems are very common within DoD where both heating and cooling are required. Forced-air systems are relatively inexpensive to install. The major components of a forced-air heating system are as follows:

a. Heating unit. Gas, oil, and coal are burned in combustion chambers which heat circulating air through heat exchanger action. In electric furnaces, filtered air is passed directly over the heating elements. Furnace makers are improving the efficiency of their products, essentially through reduced fuel consumption and minimizing the amount of heat expended as pure exhaust. Less fuel is burned when fans are used at inlet or exhaust locations to control and stabilize the flow of air which provides the oxygen for combustion. Fuel consumption can also be minimized by application of pulse combustion techniques, in which the fuel is introduced intermittently, several hundred times per minute. More efficient heat-exchanger designs incorporate new component geometry and the use of transfer fluids (glycols) to maximize the amount of heat transferred to the recirculating air. temperature of exhaust gases is reduced proportionately. When exhaust gases are cooled to dewpoint temperatures, condensation of the water vapor in the gases occurs. The condensation process gives up latent heat which can be recovered through heat exchanger action. The condensate of exhaust gas tends to become more corrosive (acidic) as combustion efficiency increases, requiring the use of resistant materials, such as stainless steel, or water dilution. Figure 16 contains examples of some basic forced-air furnace units. heat pumps, which use a reversed refrigeration cycle to supply heat, are discussed in 5.5.3.lc. New furnaces, as well as other energy consuming devices, are assigned Energy Guide ratings that are based upon the Annual Fuel Utilization Efficiency test developed by the National Bureau of Standards.

b. Accessory equipment. The most common accessory is the air filter, which is usually located in the return supply duct at the furnace location. There are two general types of air filters - media and electronic. The media type are relatively inexpensive and are either cleanable or disposable. The electronic variety are more costly, but provide better filtering. Electronic filters are normally fitted with a signaling capability that indictes when cleaning is required. Air filter efficiency ranges from 20-percent ASHRAE dustspot test for the simplest media type to over 90-percent for the best electronic devices. The humidifier is another common accessory which introduces water vapor into the air flow to restore the relative humidity of the warm air up to a desired level. The water vapor is introduced in a variety of ways, from merely passing the circulating air over a pan of water to injecting steam into the air flow, During cold weather, the introduction of low humidity outside air for ventilation can significantly increase the humidification required to maintain design conditions. Humidification must be carefully monitored to preclude damaging condensation. Supplemental heat sources, from either energy recovery or solar collection, can be employed to add warm air to the forced-air system. (see 5.5.1.5)



A. ELECTRIC FORCED-AIR FURNACE



B. WARM AIR FORCED-AIR FURNACE

FIGURE 16. Forced-air furnace units.

c. Distribution network. The blower and ductwork of a forced-air system distribute warm air to the various rooms and spaces of a building, and supply cooled, recirculated air, and make-up air to the furnace to be filtered and reheated. The blower will provide either a constant or variable air volume to the spaces to be heated. Ducts are either rectangular or round in cross section, and are fabricated of metal or fiber glass. The recent introduction of glass fiber ducts and coiled-steel duct “L” sections has cut HVAC installation costs or permitted larger ducts for the same price. The larger ducts make low pressure (l-inch water-gauge pressure or less) Systems possible with a large savings in energy costs. Low pressure systems tend to be easier to control, modify, and balance when compared to high pressure ones. Specially designed ductwork, which is flexible and small in cross section, is ideal for retrofit installations, where space is limited. Ducts are insulated, when not in a conditioned space, to reduce heat losses along the duct run. Dampers are installed inside individual duct sections to direct and control the flow of air. Controlling the flow of air to achieve the appropriate temperatures in building spaces is called “balancing the system.

d. Controls. A number of automatic or manual devices, which are located throughout a building, monitor temperature, humidity, and air flow. tolerances are exceeded, these control devices activate the heating and cooling systems, humidifier, dehumidifier, ventilator, as required. Continuous recording of indoor climate is highly recommended for information services facilities, so that mission equipment error rates and failures can be correlated with environmental conditions. Control devices are discussed in 5.7.

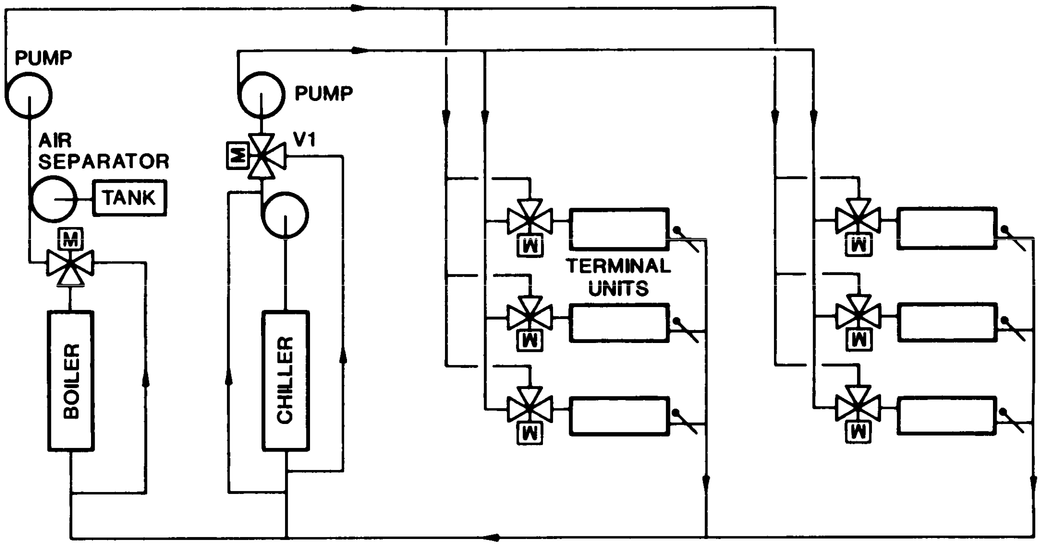
5.5.1.2 Hot water systems. Hot water systems are commonly used for heating large facilities, especially where individual rooms or areas of buildings have different heating (and cooling) requirements. Temperatures in a hot water network may exceed normal boiling points, but internal system pressures keep the water from flashing to steam. Hot water systems are generally classified according to operating temperature: low (below 250 °F (121.1 °C)), medium (250 °F to 350 °F (176.7 °C)) or high (above 350 °F). Typical operating pressures for low, medium, and high temperature systems are: low - 30 psi (200 kPa); medium - 150 psi (1030 kPa); and high - 300 psi (2100 kPa). A design water temperature and flow rate must be established for the system. The domestic hot water supply is often provided by the central heating system. The major components of a hot water system, which are similar in purpose to those found in forced-air systems, are as follows: a central heating unit, accessory equipment, a distribution network, room terminal devices, and controls.

a. Heating unit. In hot water systems, the centrally located heating unit, which uses a coal, oil, or gas combustion device (firebox) to heat water, is called a boiler. In hVAc parlance, the term “furnace” is applied to forced-air systems. Just as with forced-air furnaces, heating units of hot water systems are being constantly improved to provide greater fuel efficiency. Hot water systems can also use electricity or solar energy as heat sources. Boilers are classified according to a number of parameters, including size, operating temperature and pressure, shape, and type fuel used. They are usually made of cast-iron or steel. Cast-iron boilers'are fabricated from sections which are fastened together to form a unit of desired size. Steel boilers are individually made in given sizes. Domestic hot water service may be provided by heat exchanger action on separate coils. The domestic hot water service is usually tankless, unless the demand is high.

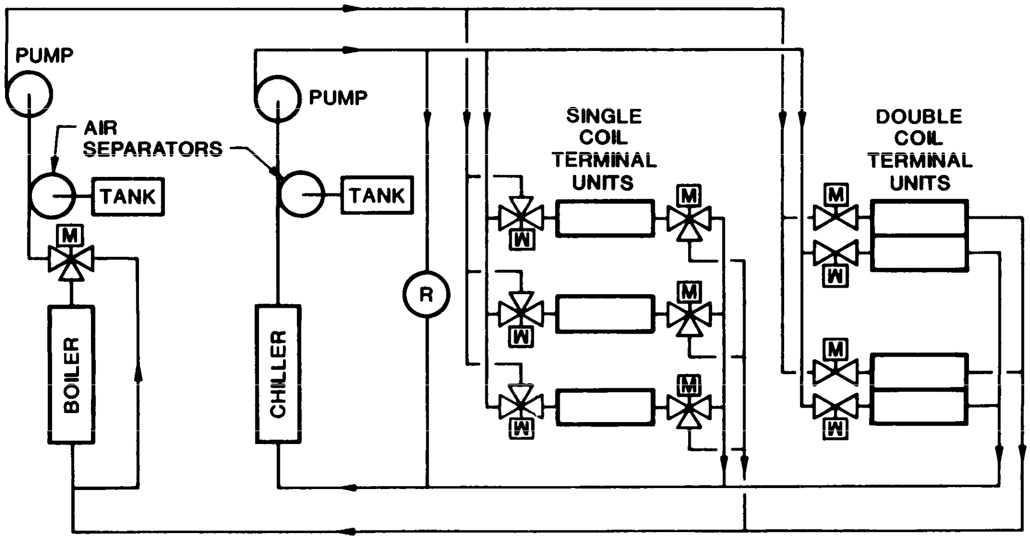
b. Accessory equipment. Because hot water systems do not provide for the control of humIdIty and ventilation as readily as do forced-air systems, extensive accessory equipment is often furnished for that purpose. Ventilation methods can range from simply relying on the natural infiltration of outside air to employing an elaborate, central air circulation network. Natural ventilation is ordinarily dependent upon the negative pressure produced by exhaust fans, and brings in unfiltered air with uncontrolled humidity. Some improvement can be obtained by providing damper-controlled and filtered apertures on building rooms and spaces with outside walls. The best results are realized with mechanical ventilation systems that circulate filtered and humidity controlled air through ductwork, paralleling the heating system. Humidification is not normally required in electronic equipment areas, unless (1) a vapor retarder is inadequate or not provided, (2) the humidity of make-up air is below the design range, or (3) excessive dehumidification takes place during cooling. If the outside humidity is much lower than the inside design humidity and significant amounts of paper are utilized, humidification will be required to preclude the buildup of electrostatic discharge. See 5.5.4.

c. Distribution network. Pumps and a network of piping provide the distribution for a hot-water system. The pipe network may be a two- three- or four-pipe system. The three- and four-pipe systems are installed when chilled water cooling is used (see figure 17). Two-pipe networks, which are less expensive to install, can be used for both heating and cooling, but cannot satisfy the simultaneous heating and cooling requirements of DoD communications and data processing facilities. Three- or four-pipe systems allow heating or cooling action in room terminals at all times of the year. The configuration of piping network is determined by the shape and dimensions of the structure, the size and distribution of the heating load, and costs. Water flow throughout the network is controlled by mixing valves. Current National Fire Protection Association (NFPA) standards permit the use of internal sprinkler systems for hydronic heating and cooling. This option not only reduces plumbing costs, but ensures integrity of the sprinkler system.

d. Room terminal devices. The common types of room terminal heat transfer devices are: baseboard units, radiators, connectors, fan-coil units, unit ventilators, and valance units. Table XIV contains a brief description of these devices, and figure 18 contains some representative drawings. For personnel safety reasons, radiators, baseboard units, and connectors are recommended for use only with low temperature water systems.



TYPICAL THREE-PIPE SYSTEM



TYPICAL FOUR-PIPE SYSTEM

M MOTOR DRIVEN PNEUMATIC VALVE ACTUATOR

R REGULATOR

FIGURE 17. Typical three- and four-pipe networks.

5.5.1.3 Steam systems. In these systems, steam is used as the medium to move heat from a centrally located boiler to building rooms and spaces. Steam heating is often combined with chilled water cooling in a complete air conditioning package. Steam systems are classified according to temperature range, pressure range, piping configuration and flow gradient means. Operating temperatures are adjusted automatically or manually to outdoor design temperatures, and range from approximately 125 °F (51.7 °C) to 350+ °F (176.7 °c). Operating pressures vary from 0 to 125 psi (861 kPa). Most heating systems use low-pressure steam, unless a separate requirement exists for greater capacity, such as an industrial process or high volume domestic hot water service. Flow gradient means refers to the method for returning condensate (water condensed from steam) to the boiler. Condensate return may be either by gravity alone or through pump action. Steam systems are favored over hot water systems in large installations where elevation water pressure (weight) can become a problem. Also, initial installation and maintenance costs are usually lower for steam systems.

a. Heating unit. Fuel-fired boilers used in steam heating systems are essentially the same as those used for hot water systems. Made from cast-iron or steel, the boilers are sized accordiny to the temperature and pressure ranges required to meet the facility heating load.

b. Accessory equipment. Where steam heating is installed, control of indoor humidity and ventilation requires supplemental equipment similar to hot water systems. See 5.5.l.2b.

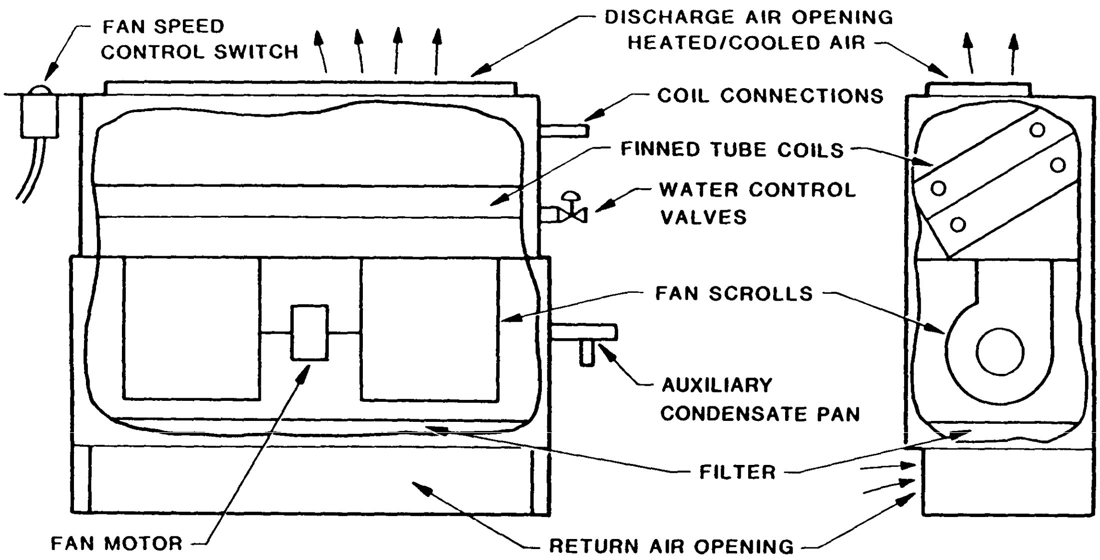
c. Distribution network. The three major functions of the piping network of a steam heating system are distributing the steam at correct temperature and pressure, returning condensate, and removing air. Condensate must be removed from supply lines and terminal units to prevent interference with steam and air flow. Normally, every effort is made to use gravity return for condensate, eliminating the installation and maintenance costs of pumps, valves, etc. The presence of unwanted air in supply pipes causes an “air-bound” condition which impedes the heating function and reduces system efficiency. A pipe network will normally have a two-pipe or four-pipe configuration, with individual pipeline functions like those described in 5.5.1.2c for hot water systems. There are some single-pipe networks in existence that release the condensate directly to drains after heat transfer in the room terminals. However, they are considered to be wasteful and inefficient, and they are not recommended.

d. Room terminal devices. Steam heating systems employ the heat transfer terminating devices used in low-temperature hot water systems (see figure 18 and table XIII).

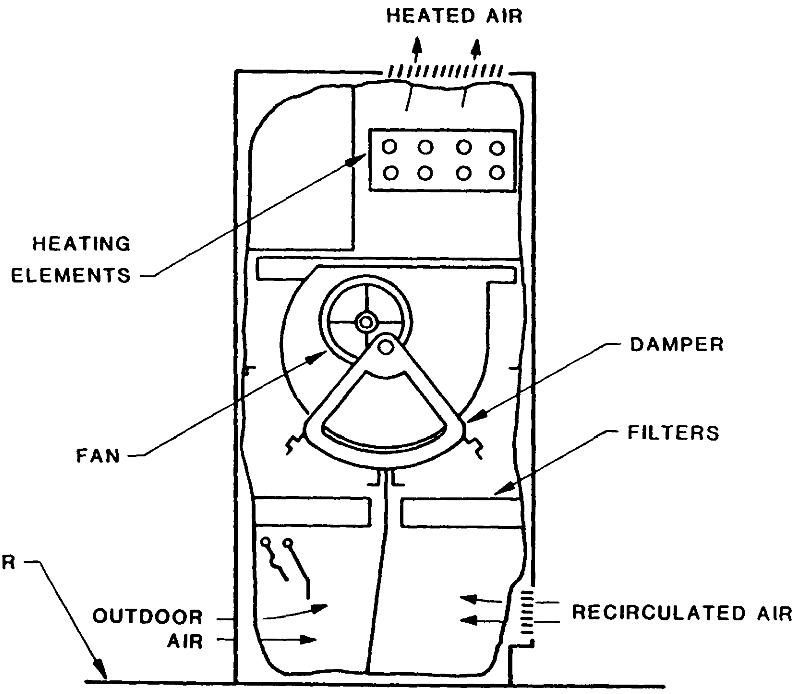
5.5.1.4 Radiant panel systems. Radiant panel systems use the surfaces of ceilings, floors, or walls as room terminals to control temperature by providing or removing heat. By ASHRAE definition, a radiant panel system provides 50 percent or more of the heat transfer function by radiation (see 5.2.10.1). The balance of heat transfer is through convection by room air movement. Radiant panels are usually arranged around the perimeter of the

TABLE XIV. Room terminal devices.

Baseboard units	Contain finned tubes or large area metal surfaces, which provide heating by the convection process of moving air and by radiation.
Radiators	Are typically either in a tube arrangement or the cast iron type commonly found in older residential buildings. They also heat indoor space by convection and radiation.
Connectors	Contain coils or panels located in wall mounted cabinets. Room air enters the bottom of the enclosure and is heated as it passes over the heating elements.
Fan-coil units	Consist of a fin-tubed coil and a fan. The fan draws recirculated room air over the coil, which contains hot water. The coil can also contain chilled water in a two-pipe heating/cooling system. A completely separate coil is provided for chilled water in a three- or four-pipe system. An air filter is usually installed, upstream of the fan. A ventilation intake and a condensate collection pan may also be incorporated into the terminal. Fan coils are rated by their air movement capacity, in cubic feet per minute (cfm) or liters per second (L/s).
Unit ventilators	Are similar to fan-coils, but have a more sophisticated ventilation capability, using outside air.
Valance units	Heat (or cool) a room or space by convection only, without using a fan. They are normally mounted high on a wall, near the ceiling. Self-circulating room air is heated by hot water in the fin-tube coil and rises toward the ceiling. Valance units have no provision for ventilation or winter humidification. Their major advantages are low cost and noiseless operation.
Controls	Room temperature regulation is accomplished by thermostatic control of coil water flow and/or air flow. Coil water flow is controlled by valve action. Air flow is controlled by varying fan speed or air bypass.



A. FAN-COIL UNIT



B. HEATING UNIT VENTILATOR

FIGURE 18. Room terminal devices.

controlled space. Radiant heating systems which use air or water are similar in design to the other heating systems previously discussed, in that they have a central heating plant, a distribution network, and accessory equipment. A separate source of filtered and humidity-controlled ventilation air must be provided. Unitary radiant panels are often used for spot heating. Infrared radiant heating systems use electric or gas-fired heaters. The infrared radiation is directed toward the areas to be heated by specially designed reflectors. Irradiation of floors is a common design practice in which the floor transfers stored heat to the space by both radiation and convection of room air. Infrared heating systems find application in large open areas, such as warehouses and industrial plants.

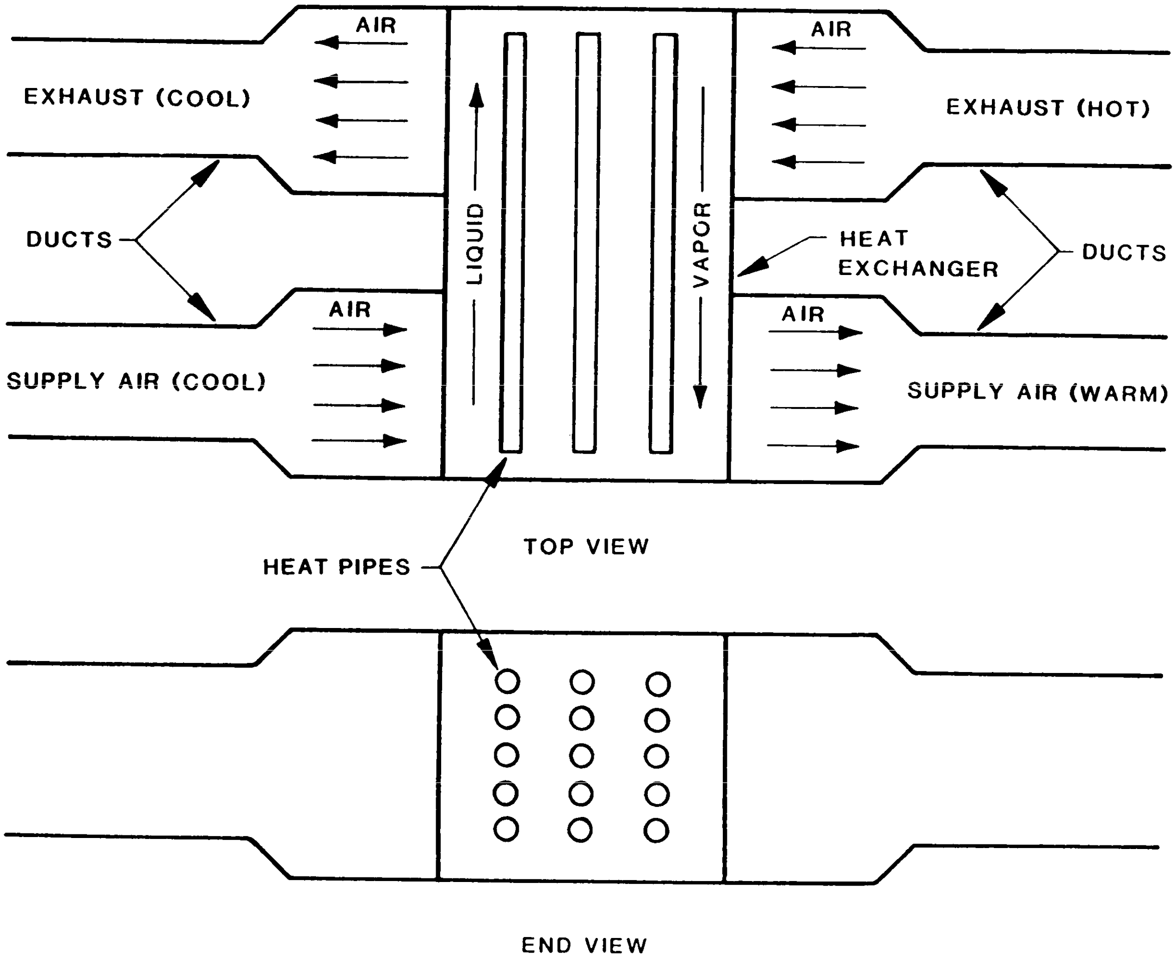
a. Radiant panels. The ceiling is the most common location for panels because it is the area least likely to be covered or blocked, it provides coverage of the entire room, and higher surface temperatures can be used. Heat is supplied to panels by circulating air or water. Panels may also be fitted with electrical resistance elements. When coils, piping, ducts, or resistance elements are installed above the ceiling, the entire ceiling surface may become the panel. Ceiling hot water systems also use coils attached to thin metal plates of varying sizes. The metal plates have excellent heat transfer characteristics and serve as part of the ceiling surface. In air systems, more commonly installed in floors, cavities are built into the space under the panel surfaces. Electrical resistance heating elements are imbedded in floor or ceiling surfaces, and find common application where spot heating is needed:

b. Applications. Radiant panel systems have advantages that make them candidates for special applications. They provide heating with minimum air movement (ventilation requirements only) and essentially noiseless operation. Circulating equipment, such as fans and pumps, are centrally located. The reduced amount of equipment within the conditioned rooms and spaces lowers maintenance costs and space requirements. Ceiling panel systems provide for maximum availability of wall and floor surfaces. The absence of wet condensation coils and fans adds to space cleanliness and sanitation. Because of these features, hospitals have been the primary users of radiant panel systems. Perimeter heating systems, using panels, are well suited for school and office buildings, where high transmission losses must be overcome. In applications where continuous cooling of equipment is required, such as computer operations, radiant panels can be used for perimeter or spot heating. Certain cautions must be exercised, however, before selecting a radiant panel system. A ceiling panel installation places constraints on the use of some lighting fixtures. While radiant panels can be used for cooling, this application is not recommended for DoD electronic facilities because of the inherent danger of condensation.

5.5.1.5 Supplemental heating systems. For reasons of economy and energy conservation all available sources of heat should be investigated. In 5.2.10.4.2 it was pointed out that heat gains may be present in a building from a variety of sources. Even during cold weather, equipment within a building and solar energy can generate large amounts of heat. This heat, which may be unwanted in one location, can supplement the output of a central heating system used in other locations or provide service hot water. Power generators and refrigeration compressors are common heat sources.

a. Heat recovery systems are grouped into two general types - balanced and unbalanced. In a balanced heat recovery system, all available recovered heat is collected and used to meet the building heating load before any demand is placed on the main system heat source (furnace, boiler, etc.). When recovered heat is greater than the heating load, the excess is stored or discarded. In an unbalanced system, all or part of excess heat is recovered without consideration of maintaining continuous system balance. Accordingly, local excesses can develop that require special equipment for removal. Heat recovery systems require careful design and precise monitoring capability. Improperly designed heat recovery systems can be self defeating and actually increase operating costs. The recovered heat energy is applied through the action of devices, such as heat exchangers, heat pipes, or heat pumps, either directly or from intermediate storage sources. According to their physical design, heat exchangers operate in air-to-air, air-to-liquid, liquid-to-liquid, or liquid-to-air modes. The heat pipe is a special type of air-to-air heat exchanger that employs the action of a heat transfer fluid to recover heat. Refrigerant material in the individual heat pipes (tubes) is heated and vaporized by the passing exhaust air. Vapor moves to the other end of the pipes where it condenses. The latent heat released during condensation warms the cool, supply air passing over the pipes. Condensed refrigerant returns to the evaporation end in a wick, which lines the tubes. A heat pipe operates in a continuous cycle, with no moving parts. The amount of heat transferred by a heat-pipe heat exchanger is controlled by adjusting the angle of the pipes with respect to the horizontal plane. When the evaporator end is lower, recycling time of the refrigerant is reduced and more heat is transferred. Figure 19 shows some heat exchanger applications, including the heat pipe. A heat pump is a device that uses the compression refrigeration cycle to remove heat from a source (air or liquid) and applies it to a useful purpose. The theory and operation of heat pumps are explained in 5.5.3.l.c. Paragraph 5.8.2 contains additional information on energy conservation heat recovery.

b. Solar heating systems have gained popularity in recent years with the increased costs and problems associated with fossil fuels. Economical warm air or hot water heating can be provided from solar energy, but a secondary or back-up system must, of course, be available to support continuous or time sensitive activities. Solar systems are classified as either active or passive. Active systems, sometimes called indirect systems, use some other energy source to move heat stored in a collector. The external energy is normally used to operate fans or pumps. In a passive (or direct) system, the internal space is heated directly by solar radiation, without the use of mechanical means to transfer the heat. Integrated designs, which incorporate both active and passive features, can also be found. Structures or components within the space act as solar collectors in a passive system. The structures and components must have sufficient mass to store heat. Masonry, rock, and water are used to provide the effective heat-mass, which is essential to a good solar system. With proper design, the heat-mass collects the heat during exposure to the sun and releases the stored heat during the night or during periods of cloudiness. Passive solar heating must be designed into the basic architecture of the building, while active systems can be effective as retrofit heating sources. A basic active solar heating system with hot water capability is shown on figure 20.



C. HEAT PIPE EXCHANGER

FIGURE 19. Heat exchanger applications.

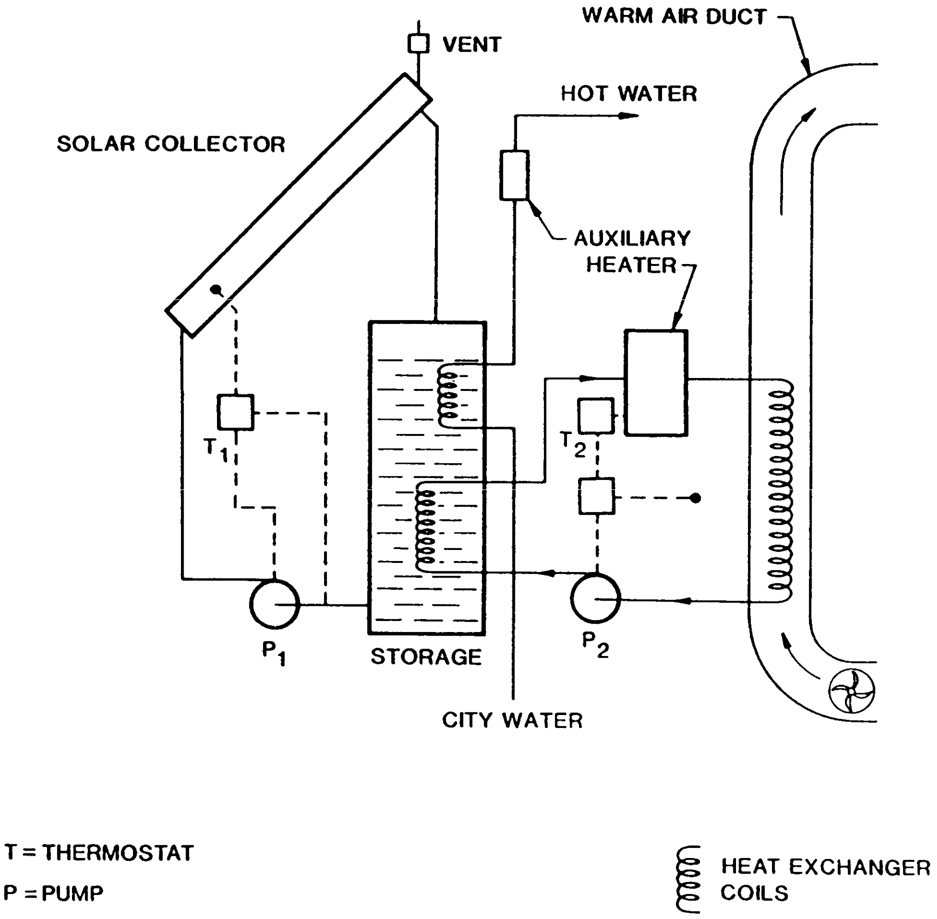


FIGURE 20. Active solar heating system.

5.5.2 Ventilating equipment. Ventilation is defined as the function of removing air from or supplying air to a space by mechanical or natural means. As one of the dilution methods of controlling indoor air quality (IAQ) (see 5.2.9.1), ventilation is usually associated with personal comfort. Through mechanical or natural means, outdoor air, which is called make-up air, is brought into a building to replace exhausted air. This fresh air thus reduces the levels of unpleasant odors and other contaminants by diluting the indoor air to acceptable levels. The amount of ventilation required depends on the rate that contaminants are being generated and the design air quality standards to be maintained. DoD communications and data processing operations do not normally produce appreciable quantities of contaminants. Therefore, ventilation requirements are limited to those levels necessary to overcome heat generated by equipment and personnel, plus carbon dioxide from human metabolism and dust or other residue from paper, tape, etc. The velocity of the air flow is also an important parameter of personal comfort. The distribution of fresh air to conditioned rooms and spaces is either direct, through opening in the building shell, or indirect, through a network of ducts. In humid locations, fresh air should always be introduced ahead of the cooling coil.

5.5.2.1 Ventilation standards. The Government and civilian industry are developing standards that will strike a better compromise between IAQ and energy conservation. Based on ASHRAE Standard 62 the recommended minimum amount of fresh outside air required for each individual in a conditioned DoD space is 15 cfm (7.1 L/s).

All outside and recirculated air in electronic and other selected spaces should be filtered. The type filters used will depend on the clean air requirements of the mission equipment and activity levels being performed. Critical areas, such as those containing computers, are maintained at relatively low-temperatures by the continuous introduction of cooled air. If possible, air velocity in a critical area where personnel are seated should not exceed 50 ft/min (0.254m/s) at a level of 30-60 inches (0.76 to 1.52 m) above the floor. In other occupied areas, a maximum velocity of 0.356 m/s (70 ft/min) should be designed into the environmental control system. Rooms that house sensitive electronic equipment are normally provided with an atmospheric over-pressure to reduce the entry of unconditioned outside air. Room pressurization (gauge) between 0.05 and 0.10 inches of water (1.24 and 2.49 pa) is the accepted standard for DoD critical areas. Recommended ventilation rates for battery rooms are contained in Volume II.

5.5.2.2 Natural ventilation. The exchange of indoor air by natural ventilation relies upon the wind and thermal forces to produce the indoor/outdoor pressure differentials required for air flow. Air enters and exhausts through openings in a building, such as windows, doors, chimneys, ventilators, and other specially designed orifices. Ventilators for exhaust of contaminated air are commonly installed on building roofs to make maximum use of local winds. Winds passing over and around the ventilators create updrafts which enhance exhaust flow. Natural ventilation systems are designed for the average velocities of local winds. Exhaust ventilators should also be positioned as close as possible to the contamination sources. Thermal forces, primarily the stack effect (see 5.2.70.4), also support natural ventilation. Wind and thermal forces interact to generate air flow. Therefore, the resulting flow is not the direct sum of the pressure changes caused by each force acting separately. Special charts and mathematical formulas are available to assist in performing design calculations. Building openings for air inlets are normally located at lower levels and are greater in *cross* section than exhaust outlets. Fresh air inlets should be positioned away from exhaust outlets to preclude the re-entry of contaminated air. Monitors are installed to adjust ventilation air flow for existing wind and temperature conditions. Filtration is sometimes required especially in urban areas, where outside air contains unacceptable levels of pollution. Also, make-up air introduced into complete environmental control systems is passed through humidifying/dehumidifying accessory equipment. Natural ventilation systems cannot provide the precision control of conditioned air required by critical and technical areas, especially where computerized devices are operated.

5.5.2.3 Mechanical ventilation. Primary ventilating systems for sensitive electronic equipment rooms and spaces will be the mechanical type, involving fans and precision monitoring and control equipment. Other areas may rely on natural ventilation with a mechanical system back-up. Fans are used in mechanical ventilation systems to provide the pressures necessary to effect desired air-flow rates. As done with natural ventilation, air flow is controlled by monitors which adjust for existing wind and temperature conditions. Air flow can be controlled by on-off switching, varying fan speeds, louver settings, and other means. Economizer systems employ a control network that reduces cooling load by increasing the use of outside make-up air when conditions permit (see 5.8.3). The precise control of environmental conditions required in electronic facilities often precludes the exercise of these energy-saving techniques. Although ventilation is commonly associated with personal comfort, it is also an important factor in maintaining the temperatures, humidity levels, and pressures required by mission equipment. Accordingly, the ventilating portion of an environmental control system should not add to the cooling and heating loads by the introducing outside air, which requires excessive conditioning in the form of added cooling, humidification/dehumidification, or heating.

5.5.2.4 Fans. Fans provide the necessary pressure to move air in environmental control systems. Air pressure (static and velocity, see 5.2.7.3) is developed b the rotation of motor-driven blades or impellers. There are two general classifications of fans - axial and centrifugal - determined by the direction of air flow produced, with relation to the motor shaft. Fan performance is a function of the following parameters: fan size, rotational speed and power, mechanical efficiency, air density, pressure, and amount of air flow. A group of mathematical formulas, called fan laws, are used to predict fan performance as these parameters vary. The manufacturer normally provides performance data curves or tables with individual models of fans. Fans are selected to produce the pressures required within the duct system to provide the air volume necessary to maintain indoor design conditions. Separate fan (air handling) systems may be used to meet the requirements of different areas of a building, especially where space use patterns and heating/cooling loads vary.

5.5.2.5 Distribution of ventilation and conditioned air. Generally, air for ventilation and temperature/humidity control is distributed through a network of ducts. Ductwork is engineered to provide the required air movement within the constraints of available space, acceptable noise levels, and personal comfort considerations. The system of ducts is designed to provide specific pressures at certain locations within the network. Because of physical characteristics, such as length, cross section, number of bends-, type of material, and the use of dampers, diffusers, registers, and heat exchangers, ductwork has leaks and resistance to the flow of air. These factors are calculated in terms of static pressure losses. Fans must have sufficient capacity to overcome these losses. In many DoD electronic equipment areas, such as computer rooms, the requirement for air is relatively stable and continuous (24 hours/day). Distribution within these areas is usually from constant volume systems. In other spaces, such as administrative offices where the requirements vary according to use patterns, the changeable volume features of variable air volume systems may be appropriate (see 5.7.2.1).

5.5.3 Cooling equipment. The manufacturers of sensitive communications and data processing equipment specify the temperature and humidity conditions in which-their products-are designed to function properly. Typical ranges of temperature, humidity, and air quality are listed in 5.4.2.2.1 and 5.4.2.3.1, as summer and winter design parameters. DoD installations often include different types of electronic activities with diverse cooling requirements. For example, a communications center complex can have computer-based operations rooms and collocated radio transmitter and receiver installations for network connectivity. The cooling requirements will range from possibly none for the transmitters, to moderate with broad tolerance for the receivers, to a large, critically controlled demand for the computer rooms. Moderate cooling requirements can be met through regular central building air-conditioning systems. Computer-based facilities should be supported by dedicated, reliable, and closely monitored HVAC equipment. The environmental control system can supply cooled air from strategically located wall and floor registers, or room terminal units, to maintain the set temperature for the entire room. Occasionally, some of the conditioned air is fed directly into electronic equipment cabinetry, where the cooling loads are concentrated. This application is discouraged because supply air varies widely in temperature and will be near saturation during cooling. Neither of these is desirable for electronic equipment. Water-cooled computers usually have their own closed loop using distilled or demineralized water. This loop includes a heat exchanger which passes waste heat to a dedicated chiller using ordinary water or to a chilled water source. When chilled water is used for cooling of highly sensible loads, a delivery temperature of 47 to 50 °F (8.3 to 9.4 °C) is used. It is also a common practice to install a dedicated, unitary environmental control system within *or* near the computer room. Externally located equipment has the advantages of not taking up valuable space and of keeping most uncleared servicing and maintenance personnel out of the secure computer room. Refrigeration equipment is incorporated within the self-contained unit, and is often connected to remote cooling towers, radiators, or other heat rejection devices. In computer and other electronic installations, sensible-to-total-heat ratios can approach "1" As stated earlier in the text, cooling equipment is rated according to its ability to handle both sensible and latent heat. Special cooling coils, designed primarily for sensible loads, should be installed in these facilities. Cooling coils designed for normal comfort applications are inappropriate for highly sensible loads, because excessive latent cooling can create the need for dehumidification. Excessive sensible cooling, requiring reheat, should also be avoided.

5.5.3.1 Refrigeration cycles and equipment. Refrigeration systems are rated according to their capacity in Btu/hr, KW, or tons. The "ton' which relates to the earlier use of ice for cooling, is equal to a cooling rate of 200 Btu/min or 12,000 Btu/hr for heat removal. In HVAC usage, the term "refrigeration" is usually directed to commercial applications other than equipment cooling or personal comfort. The two basic methods of refrigeration or air conditioning, called cycles, are vapor compression and absorption.

a. Vapor compression refrigeration cycle. Figure 21 illustrates the mechanical vapor compression cycle. system components include a compressor, condenser, expansion valve, and evaporator, connected by a sealed pipeline which carries the refrigerant. At point 1, the refrigerant, in saturated vapor (gas) form, leaves the evaporator and enters the compressor. In the compressor the refrigerant is compressed by reciprocating, rotary, or centrifugal action, causing its pressure and temperature to increase. Refrigerant leaving the compressor (at point 2) has high pressure and is superheated, which means that it has more sensible heat than dry saturated vapor at a given pressure. The refrigerant loses some heat in the condenser and changes state, leaving (at point 3) as a lower-temperature saturated liquid, but still under high pressure. In the expansion valve, the liquid refrigerant is metered, appearing at (point 4) as a low pressure liquid. The actual cooling of circulating air or chilled water is accomplished by the evaporator through heat exchanger action, where heat is absorbed by the refrigerant as the liquid vaporizes. The cycle is now complete and the refrigerant is again a low-pressure, low-temperature, saturated vapor that is ready to enter the compressor to start the process again. Window air conditioners use compression refrigeration.

b. Compression refrigeration components. The compressor is the heart of compression refrigeration, in which the volume of the refrigerant is mechanically reduced to develop the required operating pressure and related temperature from compression. The compression is accomplished by various mechanical actions: reciprocating (piston), rotary, or helical rotary (screw). Compressors are rated by their capacity, in Btu/hr (W), and performance in Btu/hr (W) per input power (W). In the condenser, the refrigerant is cooled sufficiently to return it to liquid state. The cooling is accomplished by air, water, glycol, or air and water in combination (evaporation). Water is often used for heat removal in condensers of large cooling systems. The water is cooled by the heat exchanger action of remotely located radiators or cooling towers. Radiators use a stream of passing air to absorb the heat. In cooling towers, the water is sprayed over areas within the tower, where evaporation of some of the warm water provides cooling. Cooling tower shapes and internal configurations are designed to

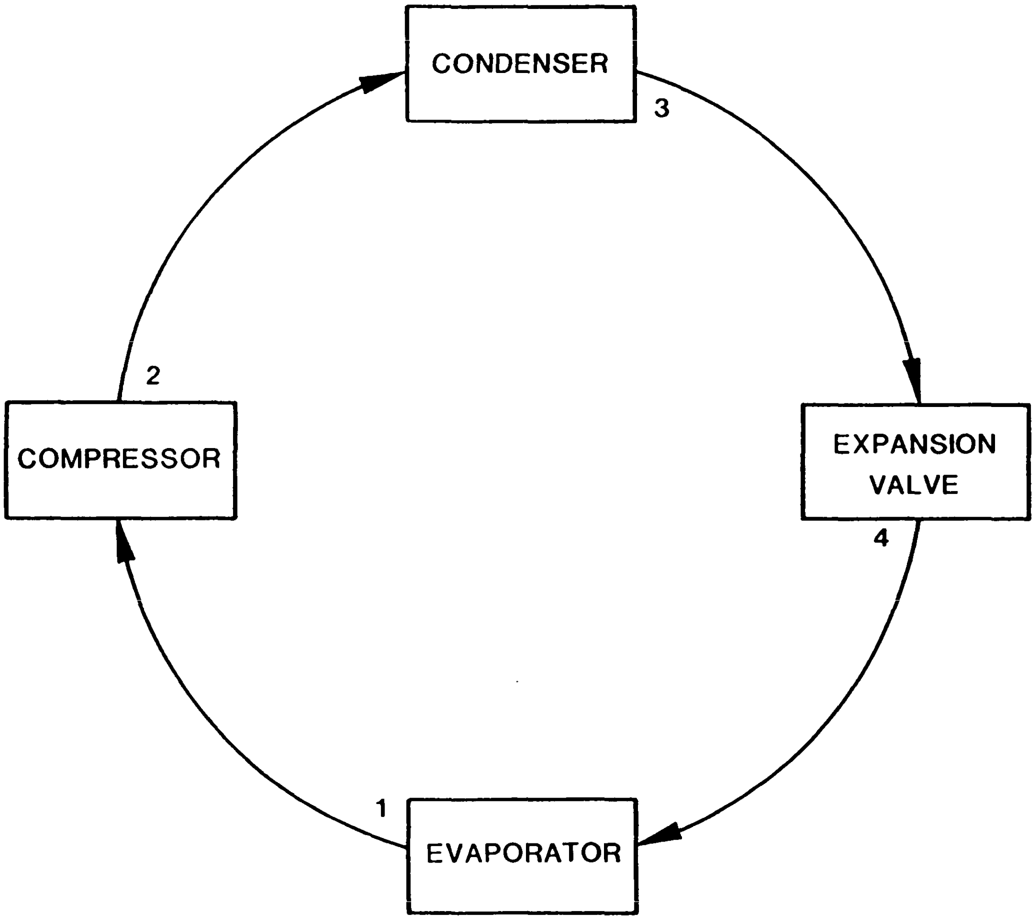


FIGURE 21. Mechanical vapor compression refrigeration cycle.

maximize air and water contact and increase cooling action. It should be recognized that using smaller air-cooled condensers with higher-temperature refrigerants is sometimes proposed to save space and initial cost. Cooling towers and evaporative condensers operate at lower refrigerant temperatures, since their operation takes advantage of the wet-bulb temperature, which can be 10 to 30 °F below the dry-bulb temperature. A significant difference in temperature also reflects a significant difference in pressure seen by the compressor. This results in large differences in required horsepower to drive the compressor. Heat removal occurs in the evaporator, where the low temperature refrigerant absorbs heat from surrounding fluid (air or water) as it vaporizes. Evaporators are also called cooling coils or liquid coolers, according to their application. In an evaporator, the tubes carrying the refrigerant are configured in a variety of ways according to their application, the refrigerants used, and the operating temperatures and pressures. The ratio of sensible to latent cooling of a coil depends upon its physical characteristics (tube size, tube rows deep, face area, fins per inch,type fin, etc.), amount of air flow, and refrigerant temperature. Refrigeration equipment selection should be based on the following design criteria:

(1) Air-cooled condensers.

Critical areas - l-percent dry-bulb temperature for summer and the 99 percent dry-bulb temperature for winter.
Technical areas - l-percent dry-bulb temperature for summer and 99 percent dry-bulb temperature for winter.

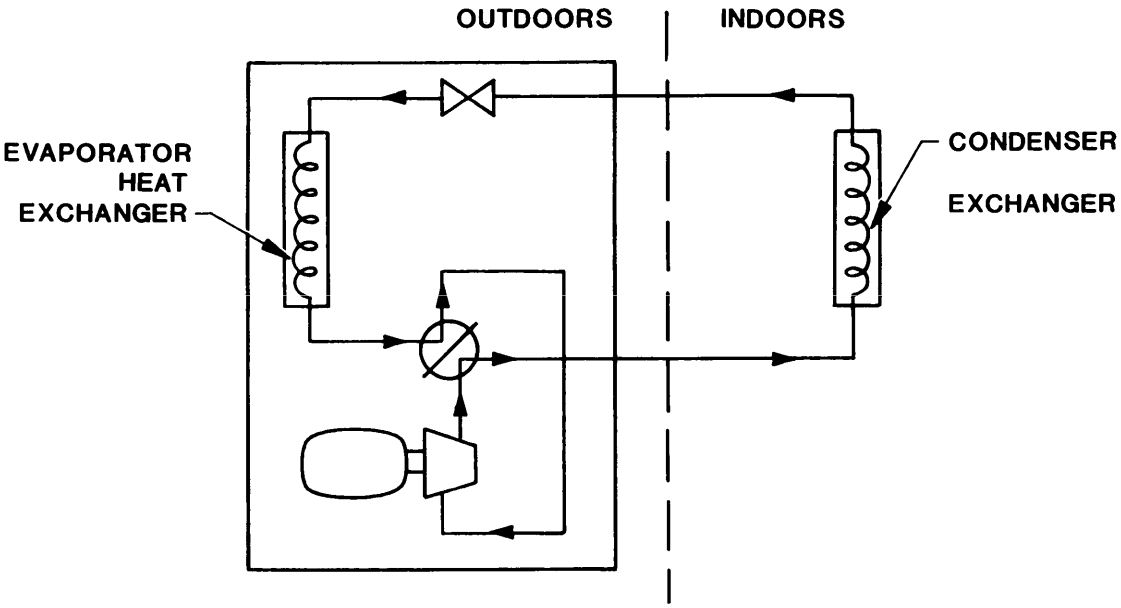
(2) Cooling towers and evaporative coolers.

Critical areas - l-percent wet-bulb temperature.
Technical areas - 2.5-percent wet-bulb temperature.

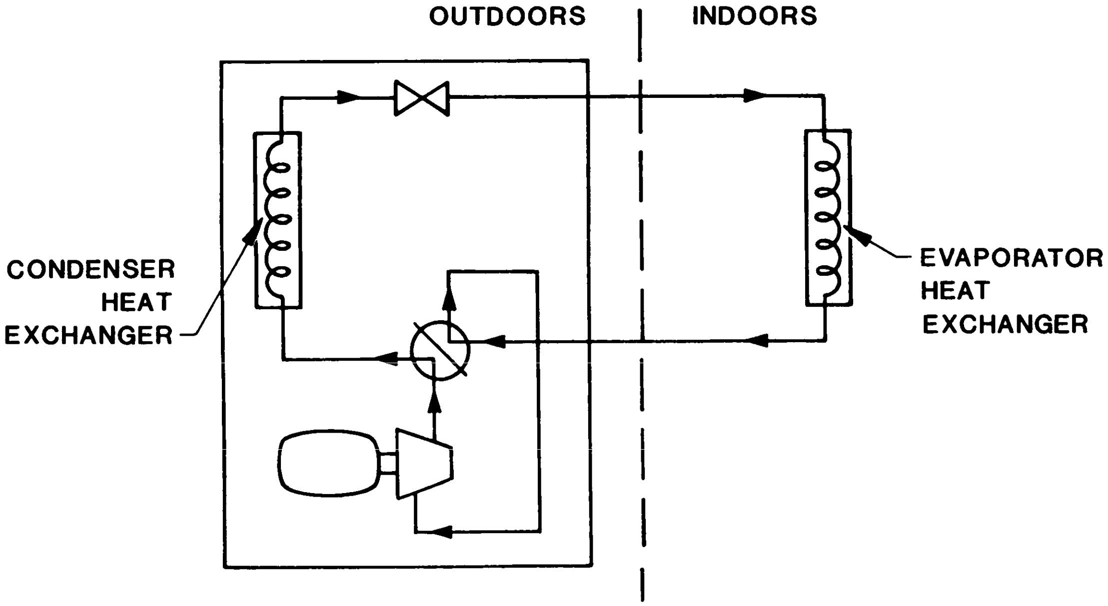
(3) Water and glycol coolers.

Critical areas- l-percent dry-bulb temperature for summer.
Technical areas- l-percent dry-bulb temperature for summer.

c. Heat pump. By engineering definition a heat pump is a device that uses a refrigeration cycle to produce useful heat. In actual practice, heat pumps are used reversibly for both heating and cooling. In simple terms, a heat pump consists of a compressor and two heat exchangers. These heat exchangers act as either a condenser or an evaporator, depending on whether the heat pump is providing heating or cooling. Refer to figure 22. In its heating mode, a heat pump provides heat from the condenser to warm indoor space. The source of heat energy is the fluid medium (air or water) surrounding the evaporator. In the heating example shown on the figure, the source of heat is the outdoor air. Even though the outdoor winter temperature may be low by comfort standards, the compressed refrigerant will take heat from the ambient air, through the heat exchanger action of the evaporator. In the cooling mode, the roles of the condenser and evaporator



HEATING MODE



COOLING MODE

FIGURE 22. Heat pump modes.

are reversed. Here, the unwanted heat within the building is absorbed by the evaporator and released to the outside air (the heat sink) by the condenser. In the examples shown, the heat pumps use a closed vapor (refrigerant) cycle in which the refrigerant is reused. Heat pumps operating with an open cycle, using available steam as the compressed vapor, are found in industrial heat-producing applications. Heat pumps are sometimes classified according to the type of transfer fluid (refrigerant) used, physical size, type of application, or thermodynamic cycle. More commonly, they are classified by the heat source and sink, and transport medium used. The most common type is the air-to-air, as shown on figure 22. Efficiency ratings are assigned to heat pumps in the form of the coefficient of performance (COP) for heating and the seasonal energy efficiency ratio (SEE) for cooling. COPS in the range of 2 to 4 and EERs in the range of 8 to 10 are common.

d. Absorption refrigeration cycle. Absorption techniques use heat energy to power the refrigeration process, rather than mechanical energy, which is used in compression cycles. As shown on figure 23, the process begins at point 1, where refrigerant vapor at low pressure enters the absorber where it is mixed with and absorbed by a special fluid, called the absorbent or transport medium. The types of absorbent and refrigerant used depend upon the amount of cooling required. Systems with a maximum cooling requirement down to 40 °F (4.44 °C) use water as the refrigerant and lithium-bromide as the absorbent. Where temperatures below 40 °F to approximately -50 °F (-45/56 °C) are required, water becomes the transport medium, with ammonia as the refrigerant. Note on figure 23 that some heat released during the absorption process must be disposed of. The absorbent-refrigerant mixture next enters the solution pump where it is transported on to the generator. An important feature of the absorption cycle is that the transporting action of the solution pump requires much less energy, in the form of work, than the mechanical pressurization of greater volumes of refrigerant vapor in the compression refrigeration process. However, significant amounts of heat must be available for absorption systems. The pressurized absorbent-refrigerant solution leaves the solution pump (at point 2) and continues to the generator, where the two constituents are separated by distillation. The complexity of the distillation process depends upon the types of absorbent and refrigerant used. The amount of heat required for distillation is approximately equal to that released during absorption. The absorbent returns directly to the absorber to restart the cycle (at point 3) while the refrigerant gas which is driven off by heat and is at a slightly higher pressure (at point 4) precedes on through the condenser, expansion valve, and evaporator. These components although different, have the same funtion as in the compression refrigeration technique. Therefore, the absorber, solution pump, and generator of absorption refrigeration serve the same role as a “compressor.” At point 5, low-pressure refrigerant moves toward the absorber to repeat the process. As previously pointed out, the absorption refrigeration process requires the use of large amounts of heat. This feature makes cogeneration very attractive economically, when heat is available from sources, such as industrial processes and engine generator exhaust (see section 5.8). Absorption refrigeration is used mostly in chilled water systems. Applications for computer rooms and other sensitive

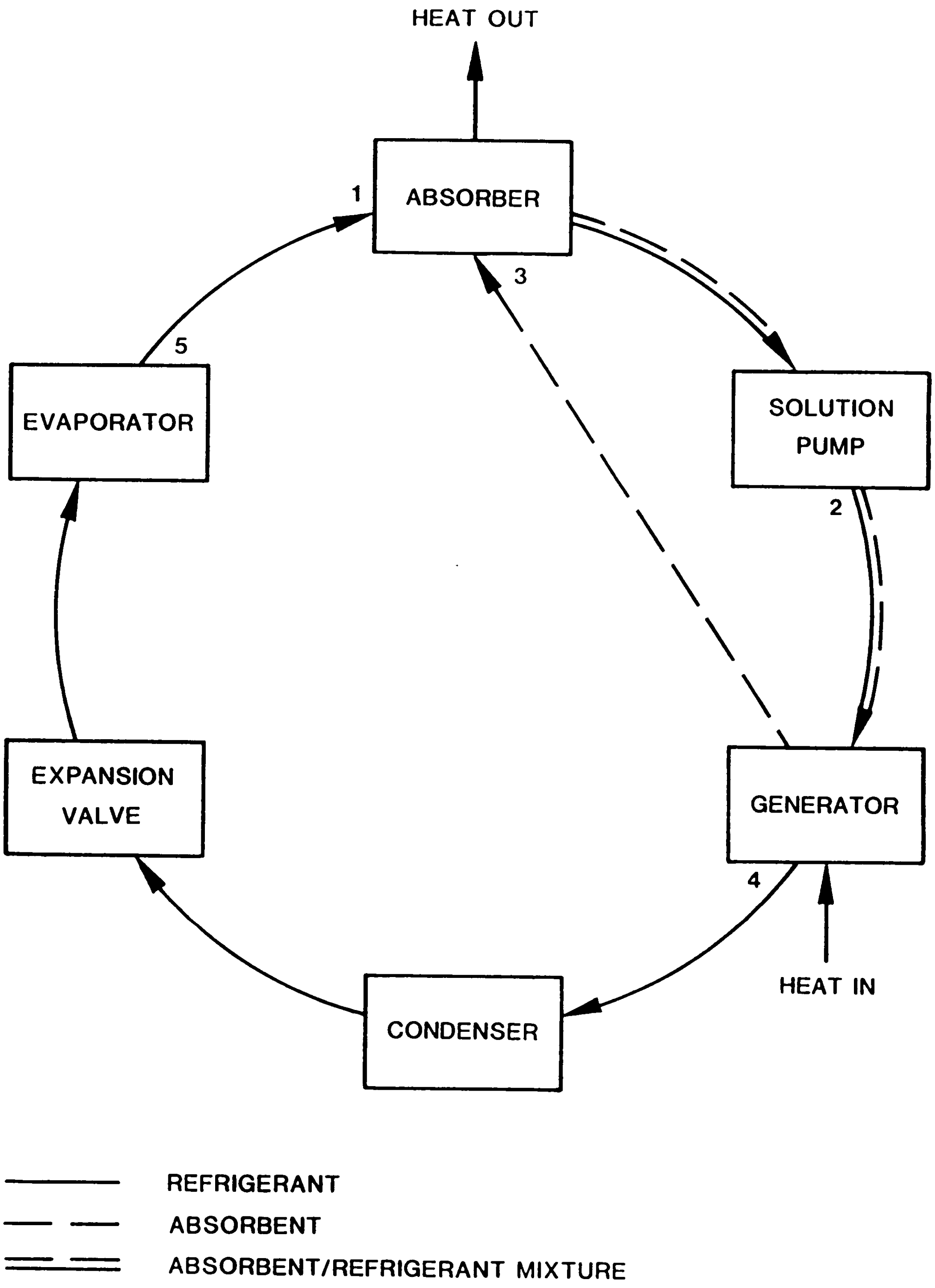


FIGURE 23. Absorption refrigeration cycle.

electronic areas use a central plant installation and room terminal devices or air circulation ductwork in the conditioned areas. Absorption refrigeration systems find limited application within the DoD because of the high fuel costs to generate the necessary heat.

e. Absorption refrigeration equipment. Absorption refrigeration equipment is classified by the amount of cooling it can provide, in tons. It can also be classified in kilowatts. Computer software, designed to assist in the selection, takes into account the characteristics of the heat source. The heat that-is released in the absorber, as the refrigerant is condensed into the absorbent, is removed by heat exchanger action of cooling water coils. The heat for the distillation process is introduced into the generator by heating coils (steam or hot liquid). In some units, heat from the absorber is recycled to the generator. Absorption refrigeration equipment is initially expensive because of its quality construction as an integral unit to maintain vacuum and internal cleanliness. Normal operation is simple and can be economical, if an inexpensive source of heat is readily available. A major consideration in the selection of this type of equipment is the availability of service and maintenance.

5.5.3.2 Evaporative cooling and equipment. In desert-like climates, where the humidity is low, evaporative devices are used for efficient, low-cost cooling. Evaporative cooling reduces the dry-bulb temperature of outside supply air by trading sensible heat for latent heat. The hot, low-humidity air is passed through an evaporating pad that is wet with water. Evaporation of the water removes heat from the air stream, so that it approaches the wet-bulb temperature. The latent heat required to evaporate the water is added to the circulating air and increases the humidity ratio of the air and water vapor mixture. Evaporative cooling is most effective when the relative humidity is below approximately 30 percent. As the relative humidity increases, the difference between the dry- and wet-bulb temperatures, called wet-bulb depression, decreases, effectively reducing the amount of cooling that can tale place. Because of the imprecise nature of evaporative coolinq and its operational reliance on outdoor weather conditions, it is not generally-suitable for the exacting environmental control required in DoD mission equipment rooms. It may have economical application in less critical spaces, such as administrative, storage, dining, and recreation areas. Evaporative cooling equipment is classified in three types: direct, indirect, and combination.

a. Direct evaporative coolers operate by passing air directly through evaporating water in a wetted-media or spray. Media pads also act as air filters. As shown on figure 24, wetted-media pads may be located on three sides of the cooler cabinet and supplied with water from piping. Media can also be sprayed with water or rotated through water baths. Wood fibers are commonly used as the media in the type of cooler shown on the figure. The pads may be chemically treated to improve their longevity, water-holding characteristics, and air filtering properties. Other types of direct evaporative coolers use media made of glass or coated fibers and nonferrous metals.

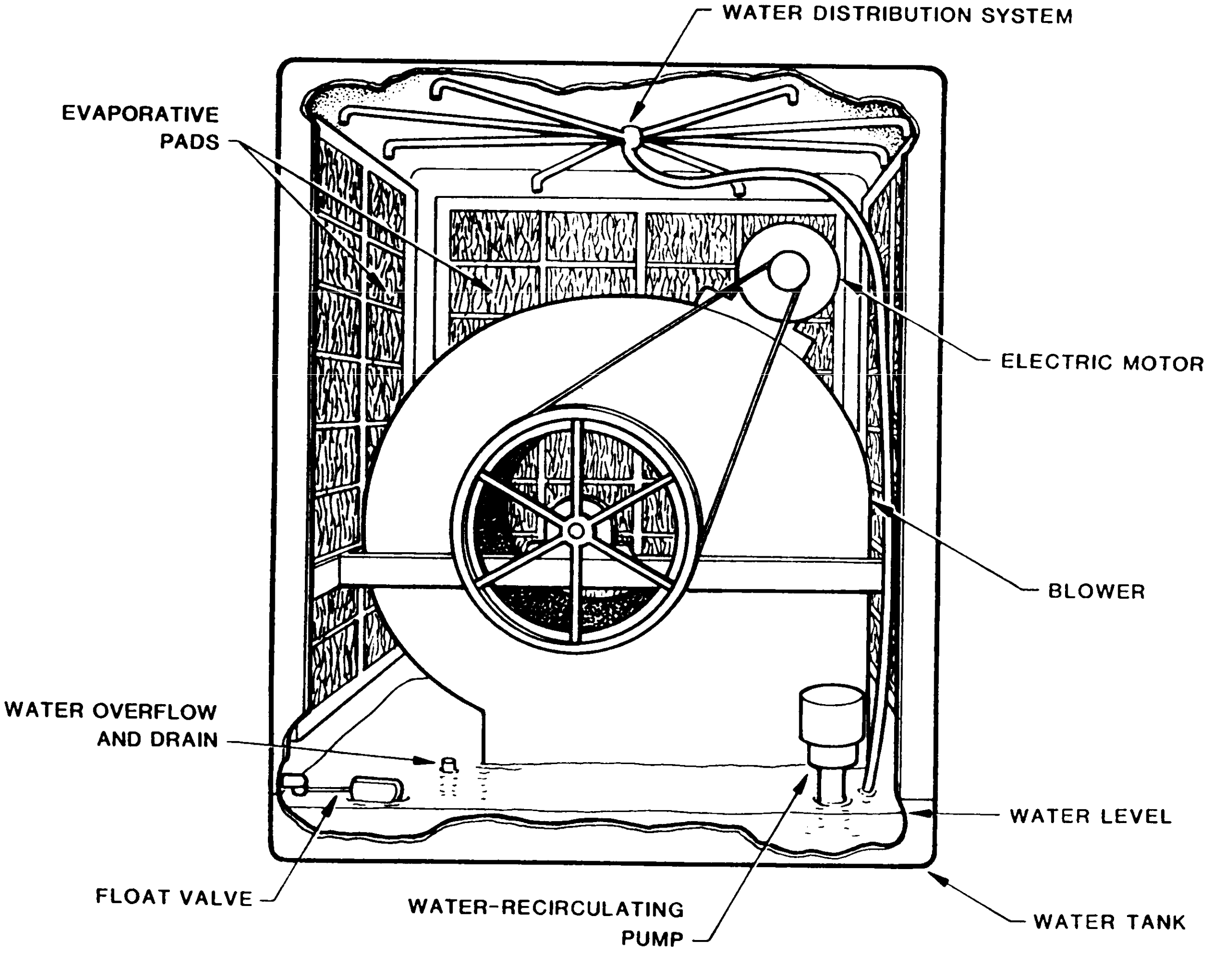


FIGURE 24. Direct evaporative cooler.

b. In an indirect evaporative cooler, supply air is cooled through heat exchanger actions, as shown on figure 25. On one side of the heat exchanger, outdoor air is cooled by evaporation. The supply air is passed over the other side of the heat exchanger and is sensibly cooled. Therefore, the supply air is cooled indirectly by evaporation.

c. Indirect and direct coolers are used in combination or stages to increase cooling action. Additional stages are sometimes used in areas with higher wet-bulb temperatures. Evaporative coolers are also used in combination with refrigerated cooling to reduce operating costs.

5.5.4 Humidity level control equipment. Local climate and the environmental conditions required for mission equipment are the major considerations in designing a humidification/dehumidification system. Controlling humidity in building rooms and spaces can be achieved through a variety of methods. Humidification and dehumidification are often accomplished during air-washing processes. Humidification methods may be as simple as pans containing water that evaporates naturally into passing air, to heated pans, and finally to elaborate electronically monitored and controlled devices that generate and inject steam into the air. As previously stated, the equipment in DoD communications and data processing facilities is predominantly electronic and produces considerable amounts of sensible heat. Therefore, a properly designed system should not require reheat during normal operation, unless significant portions of the mission equipment are not operational. Reheat is the generation of more sensible heat. In comfort cooling applications, where the latent portion of the load is much higher, it is common practice to dehumilidify by bypassing the thermostat with the humidistat to effect more cooling for more dehumidification. Concurrently, the thermostat will offset the cooling effect by calling for more heat (referred to as reheat). This arrangement does not work well in electronic facilities and total control can be lost as the system may lock into a mode from which it cannot recover. Therefore, in electronic facilites, the controls should be configured so that the humidistat calls for heat when the humidity is too high. The thermostat will then call for cooling to offset the heating tendency. This arrangement results in dehumidification by cooling and reheat, the same as the comfort cooling arrangement, but avoids loss of control. Finally, it will provide much smoother control without significant dips and swings in conditions.

5.5.4.1 Humidification. Water vapor is usually added to circulating air by placing wetted pads in the path of the air, through the atomizing action of spinning discs or high-pressure jets, which introduce mist into the air stream, or by injecting steam directly into the air. The use of steam humidification in electronic equipment rooms is desirable, assuming the steam supply does not contain minerals that would be deposited on equipment. Steam systems can be closely controlled, respond quickly, and do not create excessive moisture through “overshoot”. Centrifugal atomizing humidifiers are also recommended for use in DoD installations, if the water supply is free of suspended solids and dissolved minerals, either naturally or through filtration and demineralization. Dedicated environmental control systems for computer rooms include humidification devices.

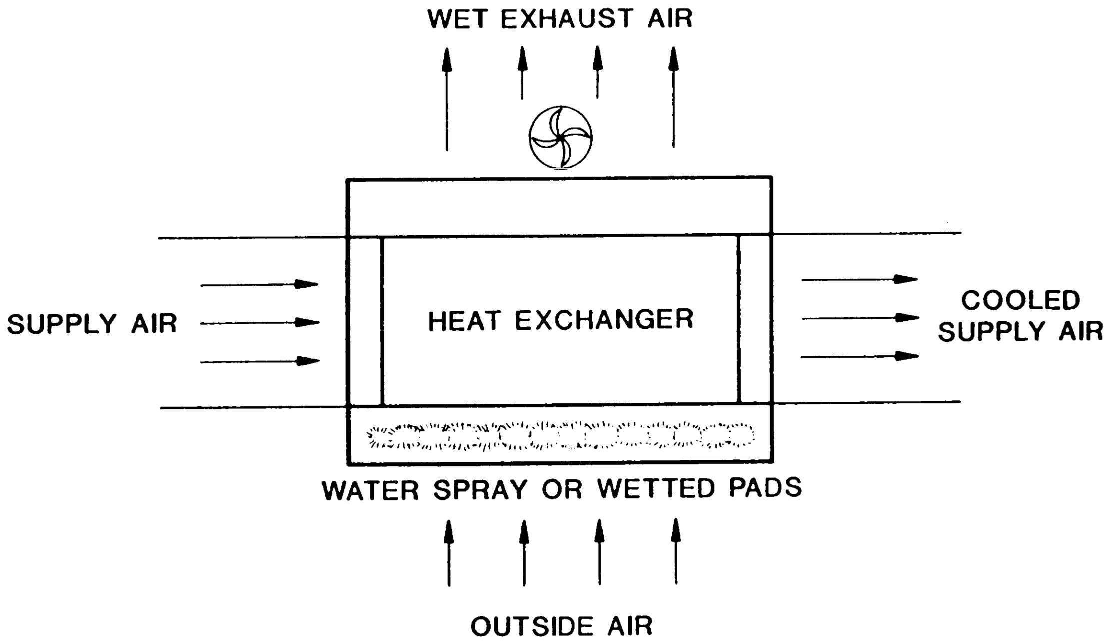


FIGURE 25. Indirect evaporative cooler.

5.5.4.2 Dehumidification. In most DoD electronics facilities, the need to dehumidify room air is small. However, in locations where extremely high humidity exists, extensive dehumidification may be required. The majority of dehumidifiers remove excess moisture by either a cooling or a sorption process (see 5.2.6c). When the temperature of the moist air is cooled below the dew point by refrigeration or cold water air washing, condensation takes place. Condensate is removed by drainage or a sorption procedure. Refrigeration-type dehumidifiers are very similar in operation to household refrigerators. Sorption-type dehumidifiers pass the moist air over trays or other surfaces that contain special materials, called sorbents or desiccants, which absorb water. In most devices, the collected water is removed from the sorption material by a heat-based drying/reactivation process.

5.5.4.3 Humidity monitoring equipment. The humidity level in a room or space is monitored and regulated by an instrument called a humidistat. In the humidistat, variations in the relative humidity are sensed by materials which exhibit proportional changes in physical dimensions or electrical properties. Changes in dimension, usually those of natural or synthetic hairs, operate mechanical switches to activate humidifiers and dehumidifiers. In the more precise state-of-the-art humidistats, sensors are circuit components which exhibit changes in resistance or capacitance and activate electronic switches. Sensors are normally positioned in close proximity to humidity sensitive devices, such as data processing equipment, or in return-air duct work.

5.5.5 Lighting. Illumination is defined as light on a surface. There are several distinct levels of surface illumination in the DoD environment. For example, there is a level of illumination required for exterior security lighting, while interior levels are functionally related to attended or unattended equipment work areas, computer terminals, and offices. It is extremely important to provide adequate lighting, but illumination above the visual comfort level wastes energy and adds to the building cooling load. Unfortunately, visual comfort is subjective: if three people enter an equipment room, one might look for the switch to provide additional light, the second might try to dim what is already on, and the third might think the illumination level is just right. As a result of these differences in perception, statistics are used to determine optimum illumination for a particular functional area. These statistics predict the percentage of personnel that are comfortable when exposed to the worst glare in a facility. This design process, called visual comfort probability (VCP), takes into account overall brightness, lighting fixture characteristics, and position, It is understandable that the determination of VCP is laborious, but computer programs are available to assist the architect or engineer.

5.5.5.1 Lighting terms, symbols, and units. This section introduces the major lighting terms, their units of measure, and how they are interrelated. Illumination quantities with their symbols and units are listed in table XV. The basic unit, stemming from the introduction of candles around 400 A.D., is the candela (cd). All other units are derived from the candela which is the unit of luminous intensity (I) of a source of light in a

TABLE XV. Lighting symbols and terms.

Symbol	Concept	Metric unit	English unit
I	Luminous intensity or candlepower	Candela (cd)	Candela (cd)
Φ	Luminous flux*	Lumen (lm)	Lumen (lm)
E	Illuminance	A lux (lx) is a lumen per square meter (lm/m^2)	A footcandle (fc) is a lumen per square foot (lm/ft^2)
M	Luminous exitance	Lumen per square meter (lm/m^2)	Lumen per square foot (lm/ft^2)
L	Luminance**	Candela per square meter (cd/m^2)	Candela per square foot (cd/ft^2)
Q	Quantity of light	Lumen-second (lm-s)	Lumen-second (lm-s)

* Luminous flux corresponds to power in the radiation system and quantity of light corresponds to energy. Thus the lumen and the watt are the same dimensionally as are the lumen-second and the joule (watt-second).

** Luminance is also often expressed in candelas per square inch and candelas per square centimeter.

NOTE: The footlambert is the unit of luminance equal to $1/\pi$ candelas per square foot. Its use is declining, but it still appears in some literature.

specified direction. Since the candle was the first standard unit of luminous intensity, later developments, such as gas flames and incandescent lamps, led to the continued rating of intensity in terms of candles. With the candela established, definition of other lighting terms and units can proceed. In figure 26a, a uniform point source of 1 cd is shown at the center of a 1 m (3 ft) radius sphere. In this case, “uniform” means that the source has the same intensity in every direction and “point” means the source is much smaller than any other dimension present. Figure 26b is an analogy where a small sphere perforated with holes is connected to a garden hose. When the water is turned on, fine streams of water travel radially outward from the holes until gravitational effects take over. This represents fluid flux. The unit of luminous flux is the lumen (lm) and is the rate at which luminous energy arrives on a 1 m^2 (1 sq yd) surface, 1 m (3 ft) away from a uniform point source of 1 cd intensity. The formula for the surface area of a sphere is $4\pi r^2$ and the total luminous flux from the source in figure 29a is 4π lm. Stated another way, a uniform l-cd point source emits 4π lm. From this, it is inferred that luminous flux is the time rate of flow of luminous energy. This also makes the lumen dimensionally equivalent to the watt, which is the time rate of flow of energy.

5.5.5.2 Example of luminous flux. As luminous flux travels outward from a source, it ultimately strikes objects where it is reflected, refracted, absorbed, or transmitted. Two or more of these characteristics are usually involved. The illuminance (E) on a surface is the density of luminous flux incident on that surface. Thus,

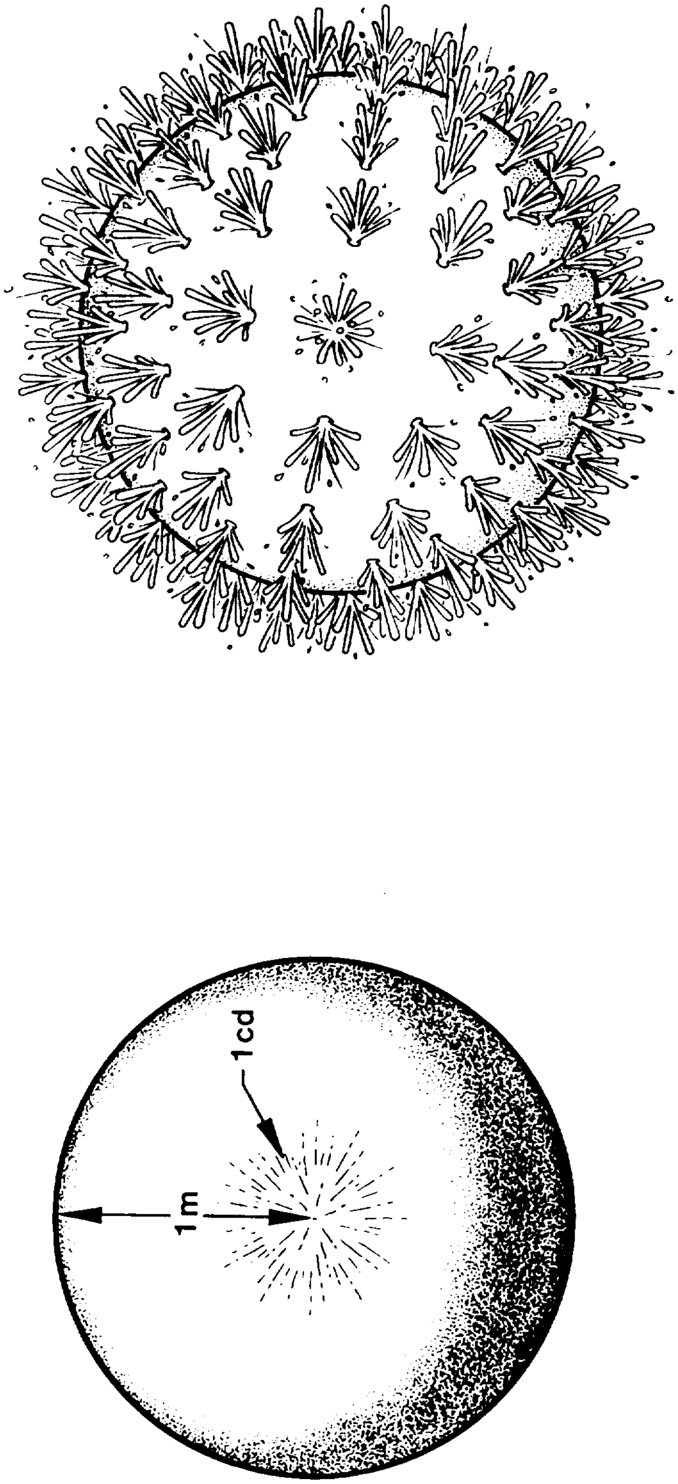
$$E = \frac{0}{A}$$

Where A is surface area.

In the SI (metric) system, the unit of illuminance is the lux (lx) and in the English system it is a footcandle (fc). A lux is a lumen per square meter and a footcandle is a lumen per square foot. The inside sphere in figure 29a receives 4π lm from the l-cd source and since the sphere’s surface area is 4π m^2, the illuminance on the inside surface of the sphere is 1 lx. This can be expressed in the English system by noting there are 10.76 ft^2 in a square meter and the illuminance is 0.093 fc.

b. If the density of luminous flux arriving at a surface is known, the next step is to determine the luminous flux leaving the surface. This requires two concepts: (1) to describe the total luminous flux leaving the surface and, (2) to describe the luminous flux leaving the surface in a particular direction. The first condition is described by luminous exitance (M), and the second by luminance (L).

c. Assume the sphere in figure 26a is made of translucent glass or plastic and it transmits 80 percent of the luminous flux it receives, reflects none back to the inside surface and absorbs the remaining 20 percent. Based on this information, 3.2π lumens (i.e., $0.8 \times 4\pi$ lm) leave the sphere and knowing that the sphere surface area is 4π m^2, the density of luminous flux leaving the sphere is 0.8 lm/m2. Thus, this sphere has a luminous exitance of 0.8 lm/m^2 or 0.074 lm/ft^2.



B. LUMINOUS FLUX ANALOGY

A. UNIFORM POINT SOURCE OF LUMINOUS FLUX

FIGURE 26. Luminous flux representative.

d. If the sphere is observed from a considerable distance, it appears as a luminous circular plane (much like the appearance of a full moon). The luminance of the sphere is defined as the intensity in the viewing direction and is obtained by dividing the intensity in the direction of viewing by the projected area of the sphere in that direction. This sphere appears from the outside as though it has an intensity of 0.8 cd with a projected area of π m^2. The luminence in this case is $0.8/\pi$ cd/m^2 or $0.074/7\pi$ cd/ft^2.

e. From the preceding discussion, it appears that luminous exitance and luminance are related through a π factor. This is not always the case, however, and is true in this example only because the sphere described emits lumens uniformly in all directions. If this example could be achieved in practice, it would be classed as perfect diffusion.

f. The next term to be considered is quantity of light (Q). Quantity of light is luminous energy and is related to luminous flux, which is luminous power through time. The lumen is the measure of luminous flux and the lumen-second or lumen-hour is the measure of light quantity. The lumen-second is useful when considering short bursts of lumens, such as flash photography. The lumen-hour is used like the kilowatt-hour in the evaluation of energy consumption over extended periods of time. In fact, lumens or light power can be expressed in watts. If all light was at the peak of the spectral luminosity curve (see figure 27), i.e., green-yellow, then

$$1 \text{ watt} = 681 \text{ lumens}$$

This relationship is used to give some insight into luminous efficency of common sources of light. For example, a 100-watt incandescent lamp emits about 1600 lumens. This means about 2.5 watts result in light and the balance is radiated as heat. A 40-watt fluorescent lamp emits approximately 3100 lumens or 4,5 watts as light and the balance as heat. This example shows that the fluorescent lamp yields almost five times the light per watt as an incandescent source. Lamps commonly known as mercury, metal halide, and high pressure sodium are included in a group called high-intensity discharge (HID). HID lamps are even more energy efficient than fluorescent, but have limited application due to their size, color rendition, and electrical noise characteristics. In this handbook, the term “luminaire” refers to the entire lighting fixture but does not include pole, post, or bracket. The “lamp” is the replaceable bulb or tube of the luminaire.

5.5.5.3 Coefficient of utilization. Early methods used to calculate interior lighting levels dealt only with direct illumination and ignored complex reflections from surrounding surfaces. In the 1920s, a standard procedure was developed that included both direct and reflected lumens. This procedure was replaced in the mid-fifties by an Illuminating Engineering Society (IES) of North America standard that evolved into the present zonal cavity method which determines average illuminance. To calculate this average, it is necessary to determine the total luminous flux reaching the workplace. The total luminous flux is composed of two components: flux directly from luminaires and indirect flux reflected from room surfaces. In

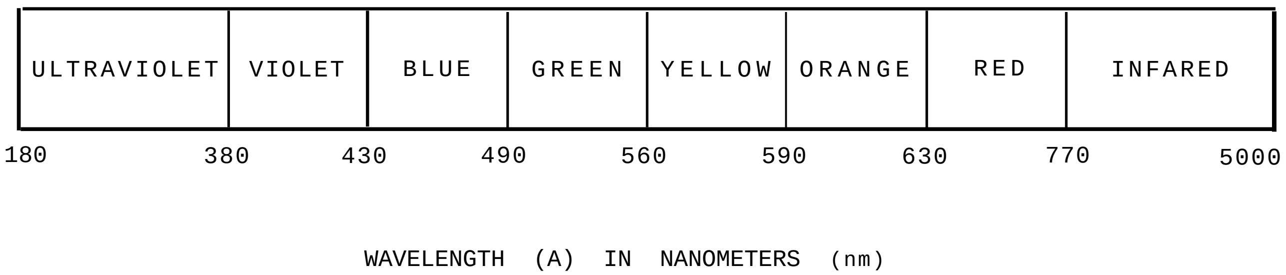


FIGURE 27. Visible and near-visible spectra.

the zonal cavity method, the fraction of the initial lamp lumens which ultimately reaches the work surface (both direct and reflected) is called the coefficient of utilization (CU). CU is defined as the ratio of useful light on the lighted surface to the total emitted by the lamp in the luminaire. CU is made up of several factors such as room size, shape reflectance, and luminaire (fixture) distribution. CU tables are published by lighting manufacturers. The concept of the lumen allows calculation of average illumination from multiple sources and considers reflections from surrounding structures.

$$E = \frac{\text{lumens generated}}{\text{area lighted in square meters}} \times CU$$

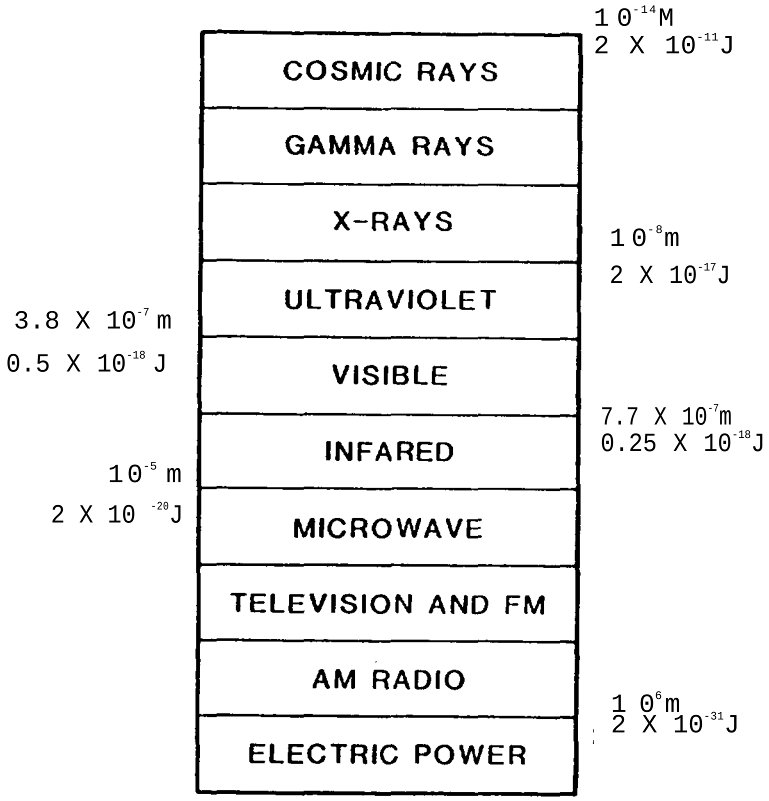
where

E = illumination in lux (English system may also be used with appropriate substitutions)

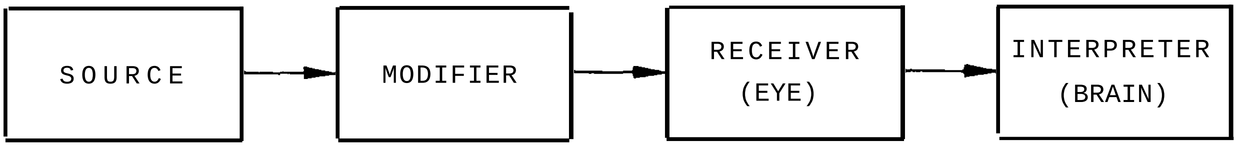
CU = coefficient of utilization

5.5.5.4 Human vision and brightness. Luminance is often confused with the popular term "brightness". Luminance is visual excitation while brightness is visual response. Brightness is a qualitative and subjective term which refers to how a surface appears to an observer. For unexplained reasons, natural light is acceptable at brightness levels that would be classed as glaring under artificial light. Brightness is not a fixed property but varies with the eye’s adaption to simultaneous and sequential contrast as well as the entire field pattern of brightness. An absolute brightness scale does exist as a mental phenomenon, but it is vague and indefinite. The eye, however, is very precise in estimating the relative brightness of two adjacent lights of the same quality. Uniform brightness is monotonous; therefore, backgrounds should have sufficient brightness and interesting contrasts. Preferred lighting installations use a combination of diffuse and directional illumination. A balanced brightness design requires engineering experience and skill.

5.5.5.5 Physical factors of seeing. The purpose of lighting in a DoD facility is to see a visual task and accomplish visual work. There are five major factors involved in the seeing recess, namely: object size, contrast, length of time the object is viewed, luminance, and color. The optimization of the first four factors of seeing creates the potential for excellence in visual performance but does not guarantee it due to fatigue, training, and other physical factors. The fifth factor, color, affects perception of objects and the spaces they occupy. Figure 28a illustrates how small a portion of the electromagnetic frequency spectrum is occupied by visible light which is called the visible spectrum. Energy produced in this narrow band will produce the sensation of vision when it stimulates a normal human eye. Figure 28b depicts the seeing process. The first requirement is a source of visible radiant energy--the sun or one of many electrical or flame sources. The next requirement is some kind of a light modifier--a natural or manufactured object that reflects or transmits light to the eye. Objects in



A. THE ELECTROMAGNETIC SPECTRUM: WAVELENGTHS IN METERS (m) AND PHOTON ENERGIES IN JOULES (J)



B. PHYSICAL FACTORS OF SEEING

FIGURE 28. The electromagnetic spectrum and physical factors of seeing.

this category are called modifiers because in most instances they will alter the spectral character of radiation from the source. The third element in seeing is the eye which serves as a light receiver and a processor before sending messages to the brain. The brain receives the signals from the optic nerve, decodes them, and provides the viewer with perception and understanding of the object.

5.5.5.6 Lighting controls. Effective lighting control is crucial to energy efficient building design since the lighting load may exceed that of installed mission equipment. The various methods used to control lighting fall in two general categories. In the first category, the light is either on or off. In the second, in addition to on and off, the amount of energy consumed and the illumination level can be varied somewhere in between the on and off state. This section discusses some of the methods used to accomplish luminaire switching and level control.

a. Snap switches. In certain applications such as warehouses, circuit breakers are used to turn off the entire lighting load. However, from the energy standpoint, this method is inefficient especially during cleaning and maintenance operations when less luminaires are required. Some states have adopted energy codes that require at least one switch per lighting circuit. In those states, the use of circuit breakers for lighting control is illegal. Mall-mounted snap switches are still the least expensive lighting control method and can be quite effective when three-way and four-way types are used to effect control from different locations. Figure 29 illustrates the simplicity of zonal and level control using wall switches to control 20 luminaires, each with four lamps, connected to a 277 volt ac source. In addition to the individual room control, the lighting in Room 100 has two levels with each switch operating one half of the lamps in each luminaire. The main disadvantage of snap switches is that they carry line voltage and if long runs are required to the luminaire being controlled, voltage drop can be a problem.

b. Time switches. The use of snap switches puts the responsibility for energy conservation on the individual. Because this is not always a reliable method, time switches can be used. With a time switch, the person entering the room turns on the lights, but does not turn them off when departing. Time switches with intervals from 0 to a few minutes or 0 to several hours are available at reasonable cost. Application of these units should be considered in such places as storage areas and bathrooms.

c. Photocells and time clocks. The controls previously discussed require human action to initiate a change. On the other hand, time clocks and photocells do not. They are ideal for use in controlling outdoor light systems. These systems are typically more expensive to install, but convenience and long-term energy savings soon offset this disadvantage. Photocells also play an important role in dynamically controlling interior illumination levels in buildings where “daylighting” is used to conserve energy. A description of how daylighting can afford significant energy savings is provided later in this section.

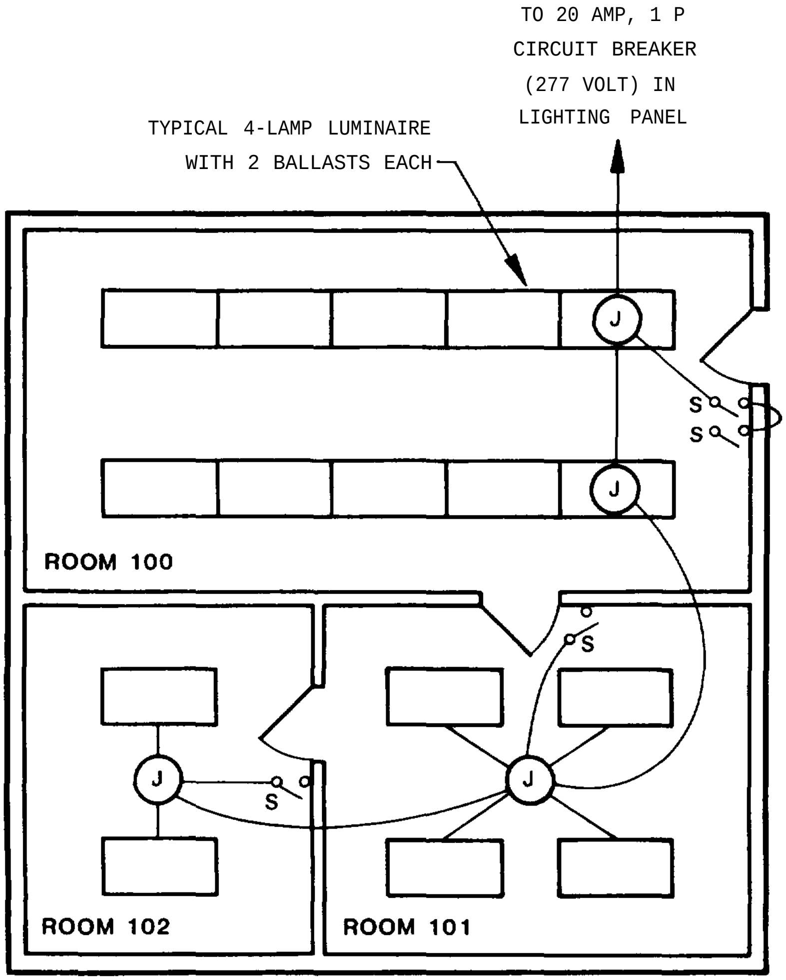


FIGURE 29. Use of wall switches for zonal and level lighting control .

d. Motion-detector switching. As previously mentioned, reliance on humans to turn lights off is questionable. In some cases, motion detectors (ultrasonic detectors) used for security systems also provide lighting system control interfaces. Motion detectors can also be used inside structures to turn on lights when an intruder (or worker) enters an area. When motion is no longer detected, an interval timer turns off the lights. This method of light control tends to be expensive but is a logical choice if a motion-detection-based security system is in place, and it is integrated with a low-voltage system as described in the following paragraph.

e. Low-voltage switching. The control of lighting using low-voltage switching Is not new, but has recently gained wider acceptance. Low-voltage switching provides the capability to control loads from a distance, control several different loads from one location, or control one load from several locations. For example, if all lights are centrally switched off in an office complex at closing time, then a local low-voltage control can be used to turn on area lights for the overtime worker. A low-voltage (usually 24 volts or less) system offers greater electrical safety, and lower costs due to the use of smaller gage wires which are normally installed without conduit. Flexibility is im roved because several luminaires can be controlled from a single relay. With the increasing use of computers to control building environment, the use of low-voltage lighting control becomes even more attractive.

f. Dimmers. Dimmers are the most popular method of illumination level control and are available for incandescent, fluorescent, and high-intensity discharge (HID) luminaires. Early incandescent dimmers were usually resistive in nature and succeeded in reducing the level of illumination but used the same power through heat dissipation in their resistance element. Recent applications of the thyristor in solid-state dimmer circuits have resulted in energy savings when luminaires are operated at reduced power. Figure 30 shows how the switching action of a solid-state dimmer results in reduced power consumption. This type of dimmer, though energy efficient, creates rf noise that may not be acceptable in the DoD environment unless special filters are included. Flourescent lamps require quite a different dimming method than incandescent. These require special dimming ballasts, a different type of electronic dimmer and special lamp holders. From the energy standpoint, the design effort to provide fluorescent dimming is worthwhile, as shown in figure 31. Dimming of HID exterior luminaires is a popular way to save energy, but because HID dimming methods cause a change in color rendition, use of interior HID dimming is limited. Figure 32 illustrates the effect on light output with variation in input power for a dimmer used on a mercury vapor HID lamp. Automatic energy management systems that incorporate dimmer controls can effect substantial savings. Energy management systems can automatically compensate for reduced luminaire outputs due to gradual lamp degradation or dirt accumulation and then signal a monitor position when the range of compensation is no longer adequate to meet illumination standards. Where daylighting is fully integrated in building design, automated dimmers reduce, increase, or eliminate artificial illumination as the natural lighting level changes.

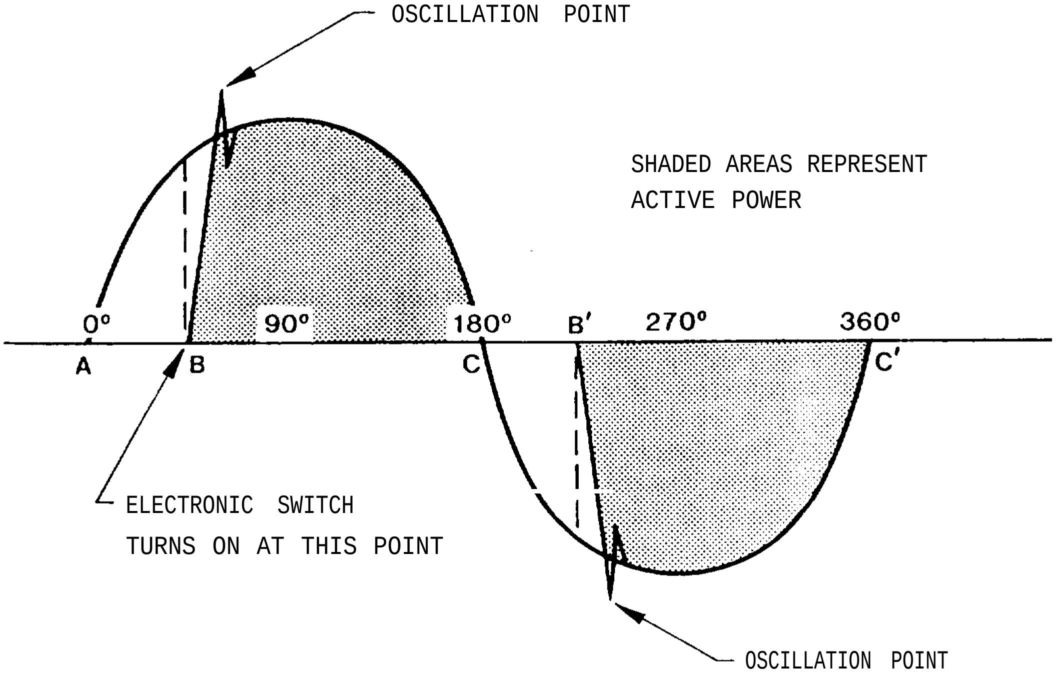


FIGURE 30. Power consumption using a solid-state dimmer.

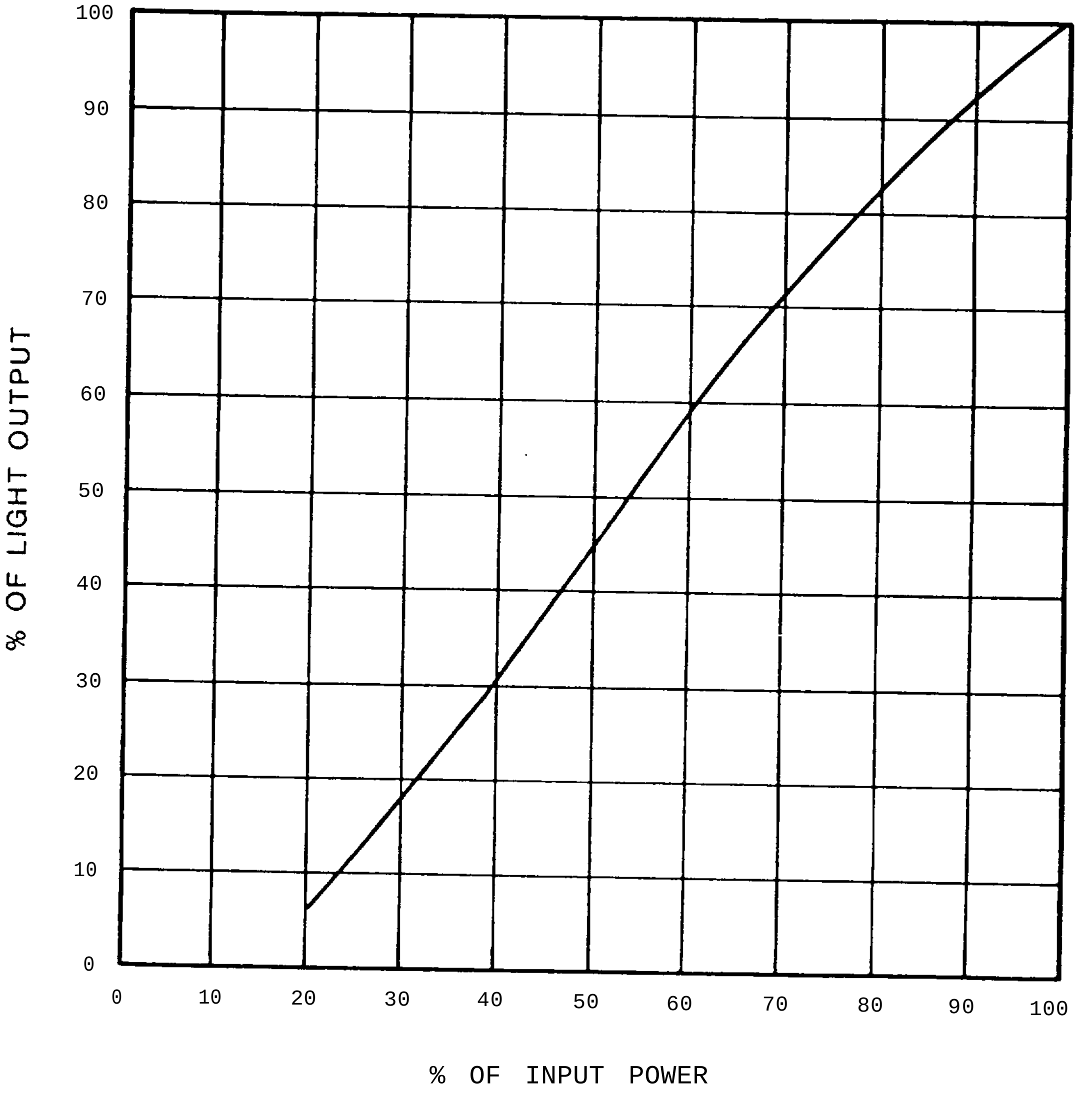


FIGURE 31. Results of using a dimmer on a 40-watt, 120-volt rapid-start fluorescent lamp.

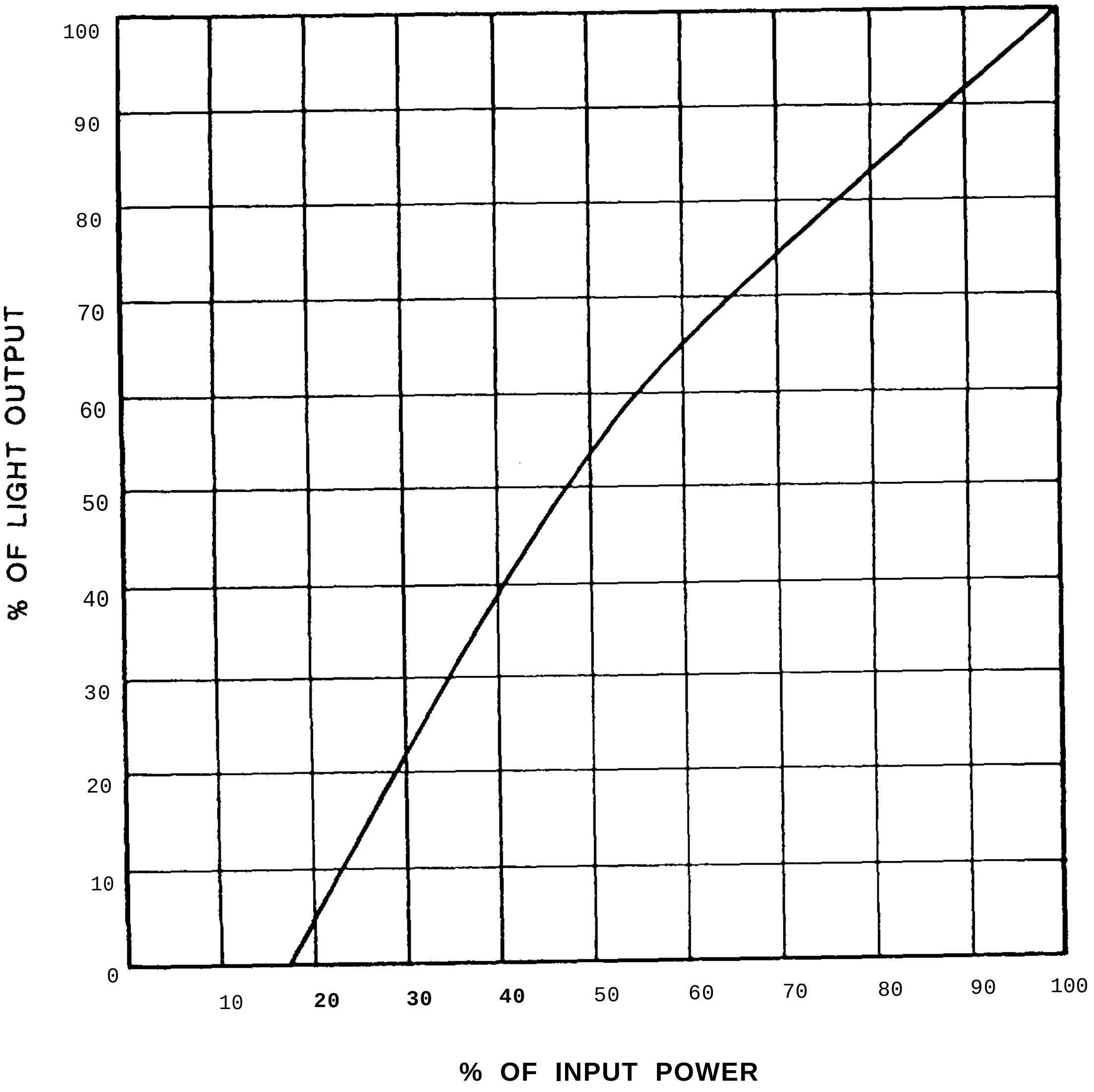


FIGURE 32. Results of using a dimmer on a 100-watt, 120 Volt, mercury-vapor light.

g. Daylighting. Daylighting, or the deliberate use of solar radiation as a source of heat and light in building design, is discussed in several parts of this handbook. This section concentrates on the visible light portion of solar radiation. Only 50 to 60 percent of the radiant energy reaching the outer limits of the earth's atmosphere actually reaches the earth's surface. Losses in radiant energy are due to scattering, reflection and absorption in the atmosphere. The earth's rotation around its polar axis causes daily changes, and rotation around the sun causes seasonal changes in the amount of radiant energy received. Figure 33 illustrates the concept of seasonal changes in the amount of solar radiation received on the surface of the earth. Daylight entering a space must be analyzed in terms of quantity and quality. Although daylight may be sufficient in quantity to reduce or turn off artificial lighting, poor quality daylight may result in discomfort and a reduction in human performance. Daylighting, in the conventional sense may not be appropriate in most DoD facilities due to the increased vulnerability caused by the fenestration (windows) required. However, a design concept for smaller facilities that utilize solar radiation for heating, cooling, and lighting, while maintaining building security, is conceivable.

5.5.5.7 Lighting innovations. Modern lighting equipment and controls cost more to install, but lower total cost results when both operating and initial costs are considered. Recent light source developments have concentrated on the HID types. Even though HID technology has brought about significant reductions in specialized lighting costs, fluorescent lamps are presently the most efficient for general lighting of building interiors. Application of solid-state circuitry to the fluorescent ballast and lamp are expected to enable this source to keep pace with future HID developments. Incandescent lamps are also undergoing significant energy-saving changes through the introduction of halogen technology. Newly developed high-pressure sodium and metal halide lamps have also resulted in increased lumens per watt (efficacy improvement).

5.5.6 Water supply and waste treatment. This section presents an overview of the primary items that are considered in the design of water supply and waste treatment systems. They include the anticipated demand, primary sources, quality standards, storage, distribution, and waste treatment. Much of the solid waste generated by DoD communications and data processing facilities is in the form of paper products. Security requirements dictate how disposal of classified waste is accomplished. Some cleaning or processing solvents may also require attention. The degree to which water supply and waste treatment considerations are included in the design of a DoD communications or data processing facility depends, of course, upon whether that facility is the sole occupant of the installation or only one of many residents. In all cases, economy, conservation, and protection of personnel and the environment must be part of the design effort.

5.5.6.1 Water usage. There are three classifications of water usage: domestic, industrial, and fire protection. Domestic uses include water for drinking, household uses, and lawn watering. Industrial uses of water include heating/cooling, irrigatio~, laundry operation, and special processes, such as industrial washing or flushing. Fire hydrant networks and sprinkler systems make up the fire protection usage. Table XVI provides estimates of domestic and industrial water requirements. The widely varying

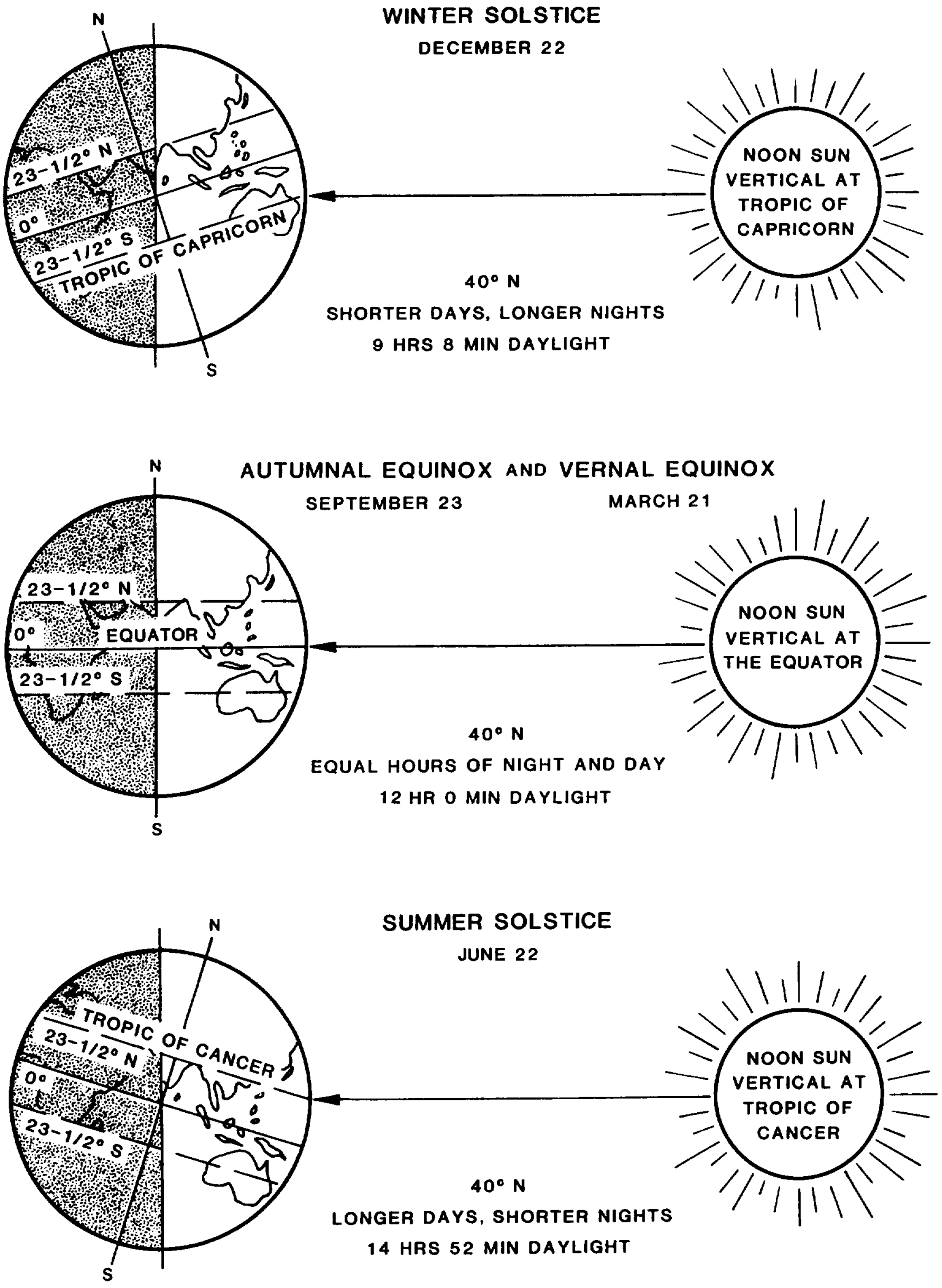


FIGURE 33. Seasonal changes in solar radiation.

TABLE XVI. Estimated domestic and industrial water requirements for permanent installations, daily gallons per capita.

DOMESTIC

Use	Requirement
Dormatories	170
Family housing	150
Workers (per shift)	50
Hospitals (per bed)	200

INDUSTRIAL

Use	Unit	Requirements		
		min	avg	max
Air conditioning:				
with conservation	gpm/ton	0.00	0.05	0.10
without conservation	gpm/ton	0.00	2.50	4.00
Cooling of diesel engines:				
with conservation	gpm/BH	0.00	0.01	0.02
without conservation	gpm/BH	0.25	2.50	4.00
Cooling of steam power plants:				
with conservation	gal/kwh	1.30	0.80	1.70
Motor vehicles	gpd/car	30	--	50
Restaurants	gal/meal	0.5	--	4.0

industrial water consumption figures shown “with or without conservation” are provided to illustrate why water conservation is desirable. Air conditioning with conservation refers to recycling of water used in cooling condensers and cooling towers, as opposed to once-through systems. There generally are prohibitions against the use of once-through systems by water suppliers, such as local Government authorities. Recycling cooling systems are recommended, with appropriate water treatment capability. In some areas, nonpotable water from sources such as wells or rivers may be available. Here also, waste water should also be treated before return to its source to limit damage to the environment. Conservation practices used with power generators are usually concerned with water reuse and lowering the operating temperature of the cooling system to reduce water losses due to evaporation and treatment. Remote radiators and cooling towers lower operating temperatures. Corrosion and scale will normally increase with higher operating temperatures, especially in closed systems from which oxygen cannot escape. The effects of temperature changes should be analyzed in terms of the type materials used in the system and the characteristics of the water supply. A water consumption and treatment plan should be based upon this analysis. Treated waste water recovered from other types of consumption should be considered for cooling applications. Parameters for fire prevention systems are at appendix B. All demands for water should be met through use of potable water, if possible. When potable water supplies are limited, to include being costly, nonpotable water may be used for industrial and fire protection uses.

5.5.6.2 Water sources. Site water will be supplied from either a local public system or from site resources, such as ground water (wells, surface water, rivers, streams, and ponds), or storage (tanks). The most desirable source is from a local public system, assuming that quality standards are met and that current and anticipated future demands can be satisfied. As indicated in 5.3, the bulk of information concerning water availability should be gathered during the site survey.

5.5.6.3 Water quality standards and treatment. Contamination of the world’s precious water supplies is a growing problem which is receiving worldwide attention. The heavy use of fertilizers and pesticides, uncontrolled dumping of hazardous wastes, and unmonitored storage of harmful substances have caused serious pollution of ground and surface water supply reservoirs in many areas. Facility designers must be concerned with ensuring the quality of available water supplies and eliminating new potentials for further pollution. Most public water supplies in the United States provide an acceptable product. The quality of water supplies in foreign countries varies and should be either verified by a recognized U.S. authority or thoroughly tested before a decision is made to use them. In the U.S., standards for domestic water quality are established by the Environmental Protection Agency (EPA). The various contaminants that may enter a water supply are classified as bacteriological , biological, chemical, physical, or radiological. Table XVII provides information concerning these classes of contaminants. Some examples of the maximum recommended levels of cormnonly found contaminants are shown in table XVIII. In locations where treatment of potable water is necessary, contaminants are removed by the application of

TABLE XVII. Classes of water contaminants.

1.	Bacteriological:	Disease-producing organisms (bacteria).
2.	Biological:	Sanitation considerations, primarily pollution from sewage.
3.	Chemical:	Pollution from toxic, nonpalatable, or otherwise objectionable substances (other than biological).
4.	Physical:	Substances, such as dirt, minerals or sediment, which may not be harmful, but make the appearance or taste of water unacceptable.
5.	Radiological:	Radio active substances present in quantities large enough to cause physical injury.

TABLE XVIII. Maximum levels of water contaminants recommended by EPA[1].

	MCL[2]
Chemicals, organic	
Benzene	5
Chlorodane	2
2,4-D	70
Dichloroethylene (1,1-)	7
Dichloropropane (1.2-)	5
Lindane	0.2
Styrene	5
Toluene	2000
Trichloroethylene	5
Vinyl chloride	2
Chemical. inorganic	
Arsenic	30
Chromium	100
Lead (at source)	5
Mercury	2
Selenium	50

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[1] Extracted from a draft version of drinking water standards and health advisories table, prepared by the EPA.

[2] Maximum Contaminant Level permitted in water which is delivered to any user by a public water system. Units are ug/1.

chemicals, such as chlorine, filtration and screening, aeration, and plain settling (settling of suspended solids in holding basins). Special treatments for the control of corrosion and scale buildup may be required. The condition of water in cooling networks of environmental control systems is articularly important, especially where water is recirculated. The build-up of scale and algae reduce operating efficiency by interfering with circulation and heat transfer functions. Corrosion damages and destroys equipment. The potential for problems varies with location and the water supply being used. The condition of cooling water should be monitored and appropriate corrective actions taken. Open systems using cooling towers or evaporative condensers lose water to evaporation, effectively increasing the concentration of contaminants. In closed systems, the level of contaminants builds up over time. In both open and closed systems, a method of draining off some of the contaminated water is provided and makeup water is added.

5.5.6.4 Water distribution. The water distribution system on a DoD facility will be installed in accordance with the appropriate military department civil engineering standards. These standards will determine the size, configuration, and burial depth of the distribution piping network, made up of arterial mains and distributors. All major water users are connected to two individual mains. Materials used in the distribution network will meet established standards for strength, hydraulic characteristics, ease of installation, ease of maintenance, resistance to corrosion, and economic considerations. Special materials and construction techniques are used in geographic areas with unique weather or seismic activity. Pumps and gravity provide the line pressures necessary to meet user requirements.

5,5.6.5 Water storage. Ground level, underground, and elevated tanks are used for water storage. Where large amounts of water are stored or there are height restrictions, ground level tanks are used. Elevated tanks are more expensive, but provide a gravity pressure gradient. For reasons of security, limited space, protection from freezing, and hydraulic grade, under round tanks are employed. Hydropneumatic tanks are a special type of container for small storage requirements. They are pressurized with compressed air to facilitate water distribution. The selection of tank materials is made with consideration of capacity, water characteristics, local weather, corrosion control, and physical protection from contaminants and sabotage.

5.5.6.6 Waste water treatment. Waste water must be properly treated before and during disposal to remove or effectively neutralize materials and substances that are potentially harmful to personnel or the environment. Certain harmful substances, such as cleaning solvents and other petroleum products, should be handled as hazardous waste and not be introduced directly into waste water drains. Waste water is generally collected and transported to a centralized treatment plant in a sewer system. The treatment plant may be operated by the DoD or by a local civilian authority. Drainage systems handling waste water are normally classified as sanitary and storm. Sanitary systems handle drainage from kitchen sinks, toilets, laundries, etc., while storm systems handle rain water from roofs, areaways, and other areas exposed to weather. Drainage from sanitary systems is routed to treatment plants.

In locations where significant amounts of rainfall and snow melt are experienced, storm drainage is routed to holding or run-off areas to preclude erosion and flooding damage. At those locations where sanitary and storm drainage are combined, separation in and around buildings is maintained until the networks are joined in an underground location. Where gravity flow is *not* possible, waste water is collected in sumps and pumped into the sewer network. Special traps and air vents are installed in drainage systems to preclude the buildup of dangerous positive and negative pressures and prevent the release of noxious or unpleasant odors. Special valves are installed to prevent flooding from reversed water flow. Devices called interceptors are installed in drainage systems to isolate potentially dangerous or disruptive substances for separation. Substances such as volatile fluids, grease, and sand are separated by interceptors. Storm drainage features that control water flow, such as ditches, swales, and holding ponds, are also called interceptors.

5.5.6.7 Domestic Hot water service. The demand for hot water in a DoD facility can be readily estimated from data available in civil engineering documentation of the military departments. Hot water is provided from storage or instantaneous devices. Storage tanks are used to meet peak demands at installations where the demand for hot water is not constant. Instantaneous devices provide a constant supply of hot water on demand. Hater is heated by the burning of fuels, electricity, solar collection, or energy recovery. Large central heating plant boilers are commonly equipped with coils for hot water service. Solar water heaters are being used increasingly with conventional systems to reduce costs. Waste heat, such as that produced by power generators, can be used to produce hot water through heat exchanger action. See 5.8.2 concerning cogeneration. Hot water is commonly stored at a temperature of 140 °F (60 °C). Where a higher temperature is required, such as 180 °F (82.2 °C) for dishwashing, some type of booster heater or separate storage tank is used. When conditions dictate, hot water systems are provided with protection against corrosion and scale buildup. Corrosion protection is provided through use of resistant materials, cathodic devices, and operation at lowest possible temperature. Water softening is used to reduce the levels of minerals that form scale. However, soft water can increase the potential for corrosion. The water supply should be carefully analyzed before equipment and protection methods are selected.

5.6 Special environmental considerations for communications and computer-based equipment. Comments concerning the suitability of specific HVAC equipment and systems for handling the environmental control of DoD communications and data processing installations are presented throughout this volume. This section summarizes special aspects and features of environmental control for these electronic installations. Volume II contains similar information on the sensitivity of mission equipment to physical damage or operational loss attributable to the electrical power systems. Critical spaces housing sensitive electronic equipment call for closely controlled temperature, humidity, and air cleanliness. Recommended parameters are provided in 5.4.2.2.1, 5.4.2.3.1, and 5.5.3.lb. Environmental conditions recommended by the equipment manufacturer should always be considered when designing a facility. The environmental control systems supporting critical and selected technical areas are also treated as critical systems. Accordingly, they should be redundant and connected to back-up power. Computer rooms should be supported by dedicated environmental control networks which control the cooling, heating, filtering, humidification, and dehumidification of room air. Figure 34 is a representation of a dedicated, self-contained environmental control system for a computer room. In this example, the area under the raised floor is used as a plenum for distribution of conditioned air. Backup may be provided by connection to central buildlng systems. The dedicated environmental control system must be designed to accommodate future changes of mission equipment size and configuration. In addition, the system must be able to sustain operations during any change or rehabilitation of mission equipment.

5.6.1 Heating. Computer-based devices, operating on a continuous duty cycle, often generate enough sensible heat to preclude the need for a full time heating system, especially in temperate climates. In locations where a permanent heating plant is not required, some form of temporary heat source must be available to maintain a temperature level of 65 “F (18.3 ‘C) when the electronic devices are not operating. The application of heat-recovery techniques, in conjunction with the operation of heat-producing electronic devices, should always be investigated in an effort to reduce energy costs. Large computer installations are candidates for heat recovery applications because of their large and stable heat generation. The temperature of the waste heat is relatively low, however, direct heat recovery may not be practical. Indirect heat recovery using double-bundle condensers on cooling equipment is one possible application. Here the fluid in the second set of coils, heated by exchanger action, can be routed for some useful purpose. The recovered energy can be used to supply heating to other parts of a building or to provide service hot water.

5.6.2 Ventilation and air quality. Computer rooms are clean spaces, normally occupied by a limited number of personnel. The requirement for outside make-up air is relatively small, only enough to maintain personnel comfort standards and a positive air pressure. Keeping the amount of make-up air to a minimum reduces the energy required for unnecessary heating, cooling, and humidity control. Filtration of conditioned air is necessary to maintain cleanliness standards. The anticipated quality of the outside air will influence the amount and type of filtration required. In locations of high pollution, such as large urban/industrial areas, special high efficiency filters and even air quality treatment may be necessary. All filtration systems should be equipped with monitoring devices which verify operation and warn of filter saturation.

5.6.3 Cooling. Cooling is the main element of the environmental control of a computer room. Computers can be either air *or* water cooled. Distribution of cooled liquid (air or water) must be designed to handle the heat gains generated by the individual units of electronic equipment. Selected areas or zones of the room will have different demands for cooling and heating. High-heat-producing electronic equipment, cooled by air, commonly includes

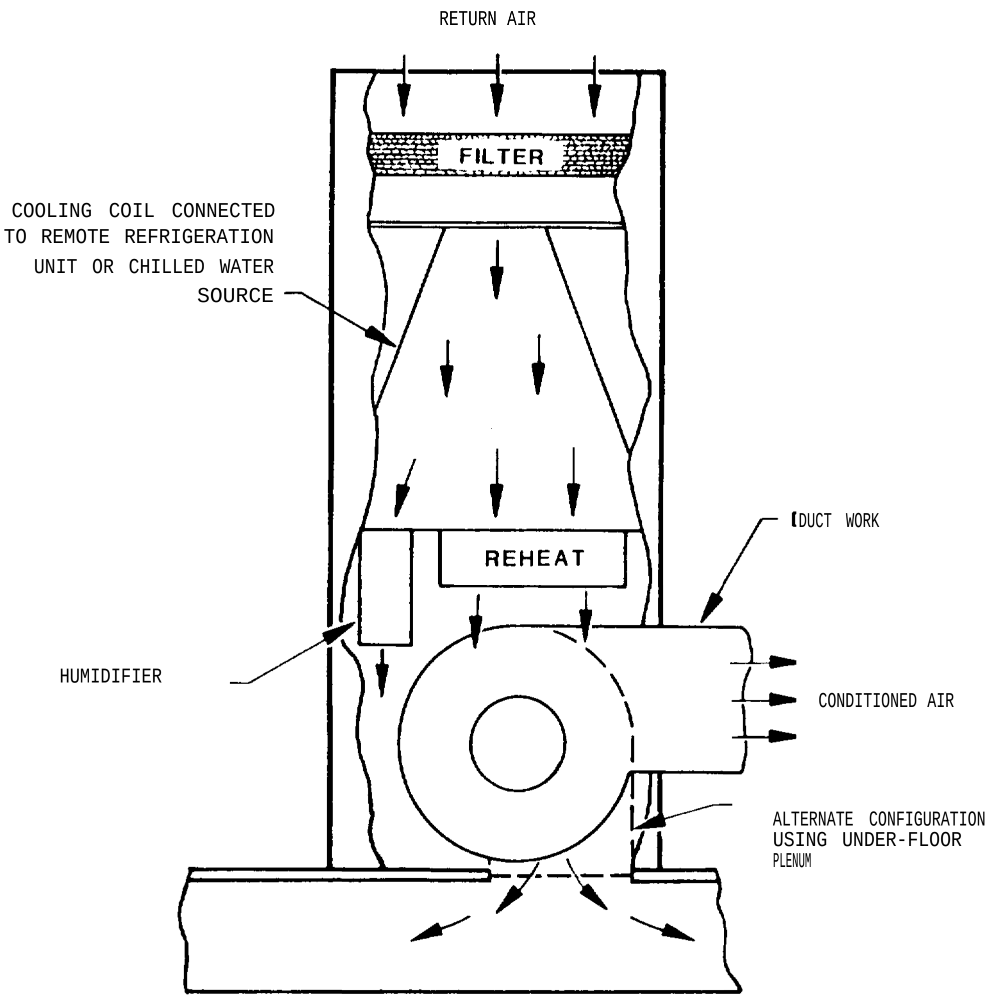

FIGURE 34. Dedicated environmental control system for computer room.

ducts and fans to facilitate the effective distribution of cooling air within the cabinetry. In common practice, conditioned air from the under-floor plenum is passed through registers located in the raised floor into the room or sometimes directly into equipment cabinets. The latter practice is not recommended, however, since supply air varies widely in temperature and during cooling will be near saturation, neither of which is desirable for electronic equipment. Also, under-floor air systems usually use more energy than above-floor applications, because of the fans or blowers required to overcome acceleration/decelerate on losses. Water-cooled computers usually include the necessary internal cooling network which is connected to an external chilled water source. Redundant refrigeration systems are sometimes provided for reliability reasons.

5.6.4 Humidity. Preserving design conditions is essential to prevent the problems that can arise when humidity levels become either too high to too low. High humidity can cause improper feeding of cards and paper, and even the formation of damaging condensation on sensitive equipment in extreme circumstances. Low levels of humidity can encourage the formation of dust and increase the potential for electrostatic discharge. If the environmental conditions called for by mission equipment permit, the relative humidity should be set at 45±5 percent, as opposed to the often-specified set point of 50±5 percent. Because the heat generated within a computer room is primarily sensible and the design temperature is low, the amount of air supplied in the cooling process is relatively high. Lowering the design humidity level significantly reduces the amount of air flow required and, in turn, the operating costs. The continuing need for cooling in a computer room tends to dry the air to relative humidities below design levels, requiring the operation of humidifiers. To minimize additional humidity losses through transmission to adjacent spaces, vapor retarders should be installed in the perimeter walls of a computer room. Openings in the room envelope for ducts and pipes should also be properly sealed. Moreover, keeping the room “tight” helps maintain correct positive pressure, which minimizes infiltration of unconditioned air. Several types of humidifiers can be found in computer installations, with the steam and centrifugal atomizing varieties being preferred.

5.6.5 Lighting. In DoD communications and data processing facilities, the use of natural lighting from fenestration is limited for security reasons. Therefore, artificial lighting is used almost exclusively for illumination. Lighting is a large source of heat and a significant contributor to the cooling load. In main equipment operating areas, lighting illumination levels should be maintained at a minimum of 50 foot-candles at an elevation of 30 inches above the floor. Additional information on the selection and application of lighting equipment for individual work stations and tasks is available in the IES Lighting Ready Reference handbook.

5.6.6 Noise. Noise levels should be maintained below 60 dbA in information systems operating areas. The provision of acceptable acoustical conditions requires that noise and vibration-generating machinery, such as power, refrigeration, or fan equipment, be carefully positioned with respect to the operating area. When environmental control equipment is located in or near the computer room which is often the case, the potential for noise pollution Is an important efement in equipment selection. Construction materials have acoustical properties that can be exploited to reduce noise pollution. For example, forced-air duct work can be designed and fabricated to reduce noise from fans and air flow. Similarly, floors and walls can be constructed with layers of air or special materials that absorb sound, and vibration problems can be reduced by mounting equipment with isolation devices.

5.6.7 Controls. Monitor and control devices are required in several strategic locations in an environmentally sensitive electronic installation. Thermometers and hygrometers constantly measure the temperature and humidity conditions inside or near sensitive mission equipment. The primary control device for maintaining temperature should be the thermostat. The primary device for controlling humidity is the humidistat. Other devices monitor the HVAC equipment, for operation within parameters, fluid leaks, degree of filter saturation, etc. These instruments should be configured and positioned so that readings are easily observed. Significant changes and faults should be made known immediately by appropriate alarms. When water *is* used as the convection medium for cooling or heating, an alarm system indicating leaks is essential, especially in the area under raised flooring where electrical and signal cabling is present. A recording capability is also very important, so that a mission equipment failure or malfunction can be correlated with concurrent environmental conditions. Software for microprocessors or PC monitoring application is readily available. The use of computers to correlate the output of HVAC equipment automatically to changing demands and to implement energy-saving techniques when appropriate, can be cost effective. Because of complexity and reliability problems, automated control of environmental systems is prohibited by some military departments at this time.

5.7 Environmental systems monitoring and control. The care and precision with which environmental systems are monitored and controlled have increased dramatically as energy costs continue to rise. All DoD communications and data processing facilities are provided with some capability to monitor and control HVAC systems and equipment. Environmental control systems designed specifically for computer room applications often include an automated control package. For all other environmental systems supporting sensitive electronic operations, a complete control system with manual override supervisory controls should be provided. Critical and some technical areas should also be provided with recording devices, so that mission equipment problems and environmental control system performance can be correlated. Control systems are composed of two basic elements, controller, and control device. A controller monitors a parameter, such as temperature or humidity, for deviations from the set point and transmits appropriate signals to initiate corrective action. A thermostat is a controller. The second element, called the control device, receives the signal from the controller and initiates corrective actions. Dampers, pumps, and valves are examples of control devices. Control systems are configured in one of two ways, open loop or closed loop. In an open loop arrangement, there is no direct relationship between the controller and the parameter being controlled. An example is a time-activated on/off switch for a cooling or heating system that operates independently of the actual temperature in the room being controlled. In a closed loop configuration, the controller monitors the parameter being controlled and initiates corrective action when deviations from the set point are observed.

5.7.1 Analog and direct digital control (DDC). The various temperatures, humidity levels, and pressures being monitored in an environmental control system are measured by a controller. When a parameter deviates from its set point a control signal is sent to the appropriate HVAC equipment. This signal may be pneumatic or electrical, such as a current or voltage. When HVAC equipment is called upon to maintain design parameters, electrical or pneumatic signals activate the controlled devices. Pneumatic devices have been used widely in environmental control, especially for proportional signaling. Proportional systems provide more accurate and energy efficient control than basic on/off systems. For some DoD applications, pneumatic control offers the advantage of reduced vulnerability to transients caused by weather or nuclear weapons. The disadvantages of pneumatic systems are reaction time and the requirement for a continuous clean, dry, air supply. As the use of microprocessors becomes more common, control of the indoor environment is evolving from analog to digital devices. The basic building block of a DDC system is the control or dedicated module (DM). DM set points (such as temperature, flow rates, start/stop times) can either be set manually using a screwdriver and gauge or by remote control from the central computer. In general, DM inputs to the control system pass through the digital-to-analog converter to the microprocessor where the control functions are performed. Changes or commands go through the analog-to-digital converter to the DM control device. Table XIX lists some of the DM types currently in use and figure 35 shows the basic architecture of dedicated modules, Highly automated electronic control systems also introduce complexity that may be beyond the maintenance ability of local resources, especially in remote or foreign locations. The relative merits of automated electronic control versus a properly designed and maintained standard system is a continuing subject of debate within the HVAC industry. Equipment selected for DoD installations should be based on maintainability and not merely state-of-the-art considerations.

TABLE XIX. Types of dedicated modules (DMs).

VAV boxes
Fan-coils
Heat pumps
Unit ventilators
Pumps
Exhaust fans
Digital input/output multiplex
Air conditioning
Evaporative coolers

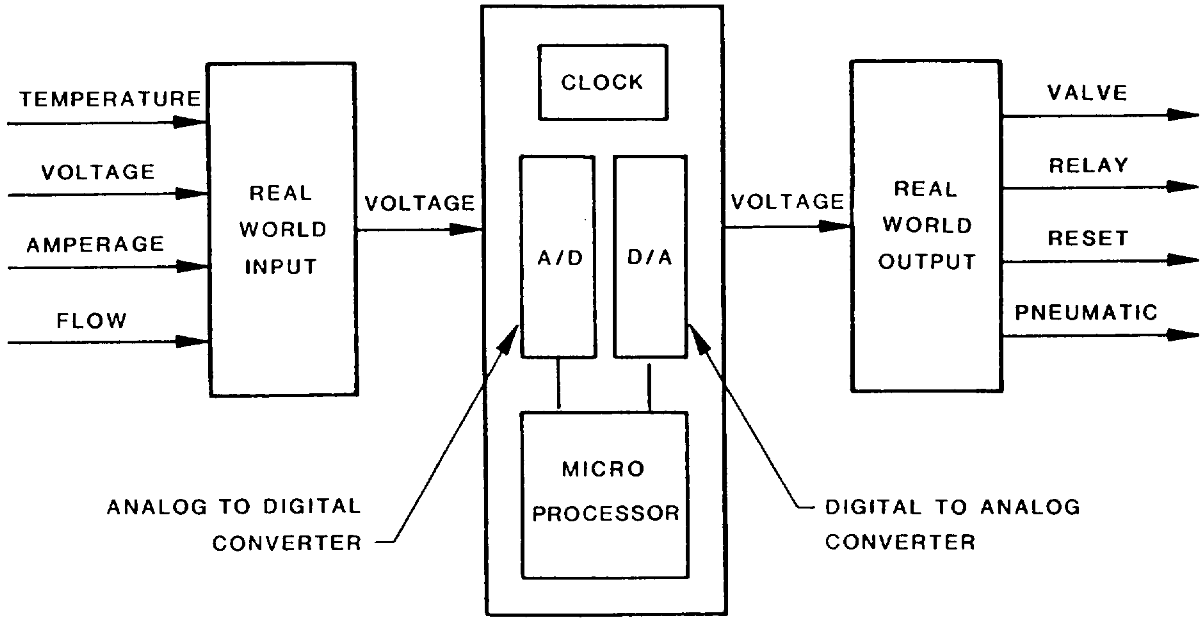

FIGURE 35. Basic architecture of dedicated modules (DMs).

5.7.2 HVAC control and energy consumption. Environmental control systems in DoD communications and data processing facilities have two purposes. The primary purpose is to provide the operating environment required for maximum reliability of mission equipment. The secondary purpose, or perhaps goal, is minimizing the consumption of energy. Most of current monitor and control techniques and practices are oriented toward minimizing energy use.

5.7.2.1 Variable air volume (VAV) systems. One of the more popular energy saving changes in HVAC techniques is known as variable air volume (VAV). In this technique, the amount of constant temperature, conditioned air that is supplied to controlled spaces is varied to maintain design conditions. This is in contrast to constant volume systems, which deliver supply air at varying temperature. VAV systems can save fan power energy in applications where the load is primarily due to outside ambient conditions. However, in electronic facilities, where the load is essentially from mission equipment and is relatively constant, the advantages of VAV systems are negated. Also, VAV systems add complexity of control at terminal devices and increase the difficulty of maintaining precise humidity control, which are disadvantages to managing the critical indoor environments of electronic facilities. In administrative and limited electronic facilities, VAV systems may be conslderea for application. VAV systems operate as follows:

a. Central fan speed is monitored by a pressure-sensing controller to maintain the supply of air needed by the conditioned spaces (zones). The central fan speed can be reduced when the collective load (all zones) reduces. The amount of supply air delivered to individual conditioned spaces is controlled by terminal devices called diffusers.

b. Multiple zoning is used to heat certain portions of a building while cooling others. There are several VAV solutions to this problem. The first is to install a complete dual duct system; however, due to expense, the trend is away from this method. The second method is to use a “smart” thermostat, VAV box, and “smart” control. Individual spaces are supplied with air from a central location through a single duct, where the VAV box provides either heating or cooling. This approach is also expensive and limited because both heating and cooling loads must be small enough for the system to satisfy them with an intermittent supply. A third solution is to create zones with "smart" VAV diffusers which can sense whetherthe temperature of supply air is heating or cooling. These diffusers sense space temperatures and modulate the supply air to meet the requirements of the conditioned space. Smart VAV diffuser systems cannot provide heating and cooling at the same time. Systems with central cooling and some form of perimeter heat are usually better for simultaneous heating and cooling. Another solution is to use a VAV box, plus either reheat or perimeter heat. Reheat can provide comfort, but is inefficient because it heats refrigerated air. Perimeter heat can be provided by baseboard, radiant panels, or fan-coil units. This method is expensive because it requires a“ separate duct for each mode. A less expensive system provides individually zoned cooling with “smart” VAV diffusers and either reheat or perimeter heat. Table XX summarizes the solutions discussed. In summary, AV systems offer significant energy savings with little impact on equipment performance, but since the amount of outside air is limited, they can result in health problems for building occupants.

TABLE XX. VAV system comparisons.

VAV system	Simultaneous heating and cooling within basic master zone	Small zones for individual comfort
Central heating and cooling:		
1. Dual duct	Yes	Not economical
2. Smart thermostat VAV box, smart control	Limited to times when both heating and cooling loads are small[1]	Not economical
3. Smart VAV diffusers	No[1]	Limited to individual control of heating or cooling, whichever is being supplied
Central cooling and perimeter heat		
4. Fan powered box		Not economical
5. VAV box and heat		Not economical
b. Smart VAV diffuser and heat		Yes

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[1] Several central units can be used to form basic master zones, each with heating and cooling.

[2] Zones can be further subzoned with smart VAV diffusers to obtain individual zones.

5.7.2.2 Integrated building automation systems. Although there currently are prohibitions against the application of automated environmental control systems within some military departments, future improvements in technology will permit the removal of these restrictions. Fully integrated building automation systems offer the potential for significant reductions in energy costs through:

a. Turning lighting and HVAC systems on and off to meet the building's occupancy schedule.

b. Reducing peak power demand.

c. Opening and closing outdoor air dampers to meet occupancy schedules.

d. Optimizing "economizer" cycles and utilizing "free cooling" when outside temperatures permit.

In addition, building automation systems can be used to control building access, diagnostic maintenance activities, and security systems. They can also be integrated with fire protection systems to control mechanical and electrical equipment during an emergency. They are a source of data for future expansion and equipment retrofits, and can be interfaced with building communications systems to provide remote access and monitoring. The functions that can be performed are limited only by the designer's imagination and whether constructive results are expected. Building automation systems that perform mission-essential roles must also meet current EMI, EMC, and EMP requirements.

5.7.3 Control of temperature. Thermometers measure the temperature of the air in rooms and ducts, and water in piping and storage tanks. Sensing changes in temperature is accomplished in a number of ways. In measurement instruments, the changes are reflected by proportional changes in the physical dimension, physical state, or electrical properties of the sensing materials. Examples of sensors include thermistors, thermocouples, capillary devices, and metallic materials, such as platinum, which changes resistance as temperature changes. Thermostats, which incorporate the thermometers, evaluate deviations from set points and initiate corrective actions as required. When heating, cooling, and humidity are being controlled, thermostats can be rather sophisticated devices. Some thermostats can be programmed with different set temperatures for separate time periods, such as day, night, or weekends. Both dry- and wet-bulb temperatures may be measured.

5.7.4 Control of humidity. The selection of humidity-sensing equipment is based upon the following factors: the anticipated range of humidity, the temperature range, and the humidity parameter to be measured. Humidity parameters include: relative humidity, wet-bulb temperature, dew point, and Humidity ratio. In electronic facilities, acceptable humidity and temperature ranges are relatively small and closely maintained. Therefore, relative humidity is usually the parameter that is measured. Controlling humidity through manipulation of the other parameters is more commonly associated with industrial processes and similar applications. As previously discussed, cooling coils for electronic room applications are designed to handle highly sensible cooling loads, reducing the need for excessive dehumidification. Relative humidity is monitored in or near sensitive equipment and in forced-air ductwork. Humidistat control is often integrated with temperature control. The thermostat should normally be the primary device for temperature control, while the humidistat is the primary device for controlling humidity.

5.7.5 Control of air and liquid pressures. Dampers and fans are used to control the flow of air into, out of, and within a building. Necessary pressures to move air within ductwork and conditioned spaces are provided by fans, operated either constantly or intermittently. Upon receiving a signal from a controller to modulate air flow, electric-motor- or pneumatic-powered actuators open or close damper blades. Actuators are sometimes called operators. Air flow must be properly balanced so that all temperature, humidity, and air quality design parameters of a facility are maintained. Adverse effects to personal comfort caused by drafts, cold spots, and hot spots must also be avoided. Forced-air systems range in complexity from single duct, single fan networks, found in private residences and small buildings, to sophisticated VAV systems found in large buildings. The increase in control function complexity is directly proportional. In hot water (and steam) and chilled water systems, valves control fluid flow. Like dampers, valves are operated electrically or pneumatically.

5.8 Energy conservation. The primary objective in designing an environmental control system for a DoD facility is to support the mission. Dedicated and redundant HVAC equipment is provided to ensure that the reliability of environmental control is commensurate with that of the mission. However, the conservation of valuable resources must also be built into the design, where possible without jeopardizing mission accomplishment. Energy consumption is a large share of life cycle costs for installations that require closely controlled environments. In the interest of minimizing life cycle cost attributed to the environmental control system, a number of areas should be addressed in planning and design, including:

a. Site selection and building positioning.

b. Exploitation of natural geographical assets.

c. Utility selection.

d. Fuel selection.

e. Building architecture, type construction, and materials.

f. HVAC equipment selection and operation.

These areas and related subject matter are presented in other sections of this handbook. This section encompasses special procedures and techniques that are concerned with energy conservation, per se. These subjects begin with a plan to manage the use of energy throughout the life of a facility or installation. Other subjects include cogeneration, economizer, off-peak operating cycles, energy-efficient construction techniques, and heat recovery methods. In each case, the applicability of the energy saving methods to DoD communications and data processing installations is considered. An energy conservation checklist is provided at appendix C.

5.8.1 Energy management program. The establishment of a continuin energy management program snould be considered for all fixed DoD communications and data processing facilities. Obviously, any program or activity which is established to manage the consumption of energy should not, in any way, Jeopardize the reliability of the mission function. However, many DoD electronic functions, especially large computer operations requiring year-round cooling, are big energy users that must be constantl monitored and analyzed to ensure that design standards and efficiency goals are being met. These facilities need a dynamic energy management program to ensure the continued cost effectiveness of the operation and to achieve the lowest life cycle costs. The environmental control system must be originally designed to be energy efficient. Comprehensive system planning will ensure that the necessary control, monitoring, and recording devices are provided.

5.b.l.l Energy manager. To improve the effectiveness of energy conservation efforts, an individual should be given the authority and responsibility to review the design. The energy manager should be involved in initial environmental system planning, if possible, but especially in design review, upgrading, and retrofit efforts. Suggested major responsibilities for the energy manager are as follows:

a. Develop and implement a public relations plan, so that building occupants understand and appreciate the objectives of the energy management program.

b. Continuously monitor and analyze energy consumption and relate results to predicted facility life cycle costs.

c. Conduct energy audits. (See 5.8.1.3.)

d. Publish scheduled reports for management. In addition to describing the effectiveness of current energy conservation efforts, the reports should make appropriate recommendations for changing or upgrading the environmental control system. Recommended changes might be the use of cheaper fuel, system configuration changes in response to mission changes, or the installation of new, more efficient HVAC equipment to reduce long-term costs.

e. Actively participate in any mission or support equipment upgrades or retrofits which will impact the environmental control system.

5.8.1.2 Monitoring HVAC equipment performance. HVAC equipment should be continuously monitored to ensure it is maintaining the correct indoor environment. Further tests are necessary to ensure that design parameters are being maintained in the most efficient manner. When both heating and cooling are being provided, for example, excessive operation of either subsystem should be avoided. Excessive heating can increase the cooling load and the need for humidification. Conversely, concurrent sensible cooling can require reheat and excessive latent cooling can require dehumidification. Parameter set points should be checked for incorrect values and unauthorized tampering. The building structure should be inspected periodically for unwanted infiltration and transmission heat gains and losses (see 5.2.10.4.1 and 5.2.10.4.2). Changes in mission performance, such as major workload variations, revised operating hours, and numbers of occupants modify the demands placed on HVAC equipment. All changes of this type, although some may seem insignificant on the surface, should be analyzed in terms of their impact on the environmental control system and energy consumption.

5.8.1.3 The energy audit and life cycle costs. Energy audits analyze and relate all aspects of the energy management program. They must do more than merely “review utility bills.” Lither important activities include verifying the performance of HVAC equipment, monitoring parameter (temperature, humidity, pressure, etc.) set points, inspecting structural integrity of the building, considering changes in building space utilization, and measuring lighting levels. Some of this information will be available from installed monitoring and recording devices. The acquisition of other data will be from specially conducted tests and inspections.

Different types of audits with varying depths and subject areas may be developed for a facility. The sizes of the facility and its environmental control system will dictate the depth and scope of energy audits. Table XXI contains potential subjects. Data produced by energy audits should not normally be the justification for major changes until a facility has been operated long enough to permit proper equipment and system shakedown. Similarly, audit results should be carefully analyzed in relation to ongoing activities or conditions before changes and corrective actions are initiated. As an example, unique weather conditions for a particular area, such as abnormally low winter temperatures, may not justify modifying the building heating plant to reduce *energy* consumption costs. Individuals involved with energy audits must have a working knowledge of the structures which house the facility, characteristics of mission and support equipment, and local climatic conditions.

b. Data received from audits and other areas of the energy management program are used to predict life cycle costs for a building or installation.

5.8.2 Cogeneration and other heat recovery methods. Heat recovery refers to the effective use of heat that is available within a facility. Cogeneration may be defined as the concurrent production of electrical power and useful application of heat recovered from a single fuel consumption process. The aim of cogeneration is to make maximum utilization of the energy released during fuel consumption. When electrical power is generated in a fuel

TABLE XXI. Subjects for energy audits.

1. NORMAL OR ANTICIPATED CLIMATIC CONDITIONS FOR THE SITE LOCATION.

Information should be available from site survey data. See 5.2.

2. BUILDING CONSTRUCTION FEATURES.

Information, such as the insulating values (U-factor or R-value. See 5.4.1.3 and 5.4.2.1) of building walls, windows, and doors should be available from construction documents and records. Obtaining information for older structures may be difficult, especially background data, such as the reasons why certain materials or construction techniques were chosen. Contract arrangements for new or retrofit construction should record all energy conservation considerations and decisions, for future reference in energy audit or other energy consumption research.

3. BUILDING UTILIZATION.

This subject includes operating hours and numbers of occupants obtained from work schedules. Anticipated numbers of visitors should also be estimated.

4 . OPERATING SPECIFICATIONS OF MISSION, MISSION SUPPORT, AND ADMINISTRATIVE EQUIPMENT.

This subject includes energy consumption data for specified equipment and activity levels for various time periods.

5, OPERATING AND PERFORMANCE SPECIFICATIONS OF ENVIRONMENTAL CONTROL EQUIPMENT.

This subject includes energy consumption data for environmental control equipment and performance specifications (amount of heating, cooling, air movement, etc. provided by that equipment).

6. RECORDS OF UTILITY COSTS.

For many DoD electronics facilities, this information will not be directly available from “utility bills.” Dollar figures may have to be estimated from equipment ratings and utility rates or fuel costs.

consuming process, energy in the form of heat is usually released. This heat can be used effectively for space heating, hot water service, or some other useful purpose. Cogeneration systems are most suitable for facilities with relatively constant demands for electricity and heat energy. The estimated life cycle costs and amount of time required to amortize the increased initial expense of installing cogeneration systems are major determining factors in any decision to employ them. When cogeneration systems require backup from utility companies, some form of agreement concerning energy exchange is required. Fuel consumption efficiencies can be improved from approximately 50 percent for traditional power production methods to around 80 percent for cogeneration. Other heat recovery methods include the heat pump (see 5.5.3.1c), heat pipe (see 5.5.1.5a), and a variety of heat exchanger applications. Energy efficient furnaces and boilers recover exhaust heat for useful application (see 5.5.1.1a). Heat released in any industrial process is a potential candidate for useful recovery. In DoD electronic installations, heat produced by equipment, such as computers and radio transmitters, offers a possible useable heat source.

5.8.3 Economizer and off-peak operating cycles. Energy consumption can be reduced by making every effort to reduce heating and cooling loads.

a. In air economizer systems, cool outside air is used to reduce the amount of refrigeration needed to meet cooling requirements. During periods of low outdoor temperatures of 50 °F or less, even if saturated, increasing amounts of outdoor air can be drawn into a building to provide cooling. Outside air at this condition is equal to or better than the normally supplied refrigerated air. Unwanted humidity can also be introduced if higher temperature air is used. Economizer systems require larger fresh-air intake openings, larger filter banks, motorized dampers, ductwork, and complexity of the control function, especially where close tolerances must be maintained. Application of economizer cycles for environmental control of DoD electronic installations, therefore, must be carefully evaluated and limited to those locations where the reliability of the mission is in no way jeopardized.

b. For off-peak operating cycles change temperature setpoints during periods of reduced occupancy or operation, such as nighttime or weekends, to reduce heating and cooling loads. While this practice is generally not appropriate for electronic facilities, especially those which operate on a 24-hour basis, it should be considered for less critical support and administrative areas.

5.8.4 Energy-efficient construction. Heating and cooling loads can be minimized by using architectural designs, building materials, and construction techniques that are matched to the local features of the site. Building designs should consider the following items:

a. Site orientation to take maximum advantage of terrain features.

b. Architectural design appropriate for the geographical location.

c. Control and use of solar radiation.

d. Protection from adverse winds.

e. Use of insulation and vapor retarders.

f. Smart selection of HVAC equipment and systems.

5.9 Environmental systems upgrade planning. Upgrading the environmental control system of a DoD facility involves either retrofitting or replacing existing HVAC equipment. Action may be required because existing equipment is worn out, has insufficient capacity, or is too difficult or expensive to maintain. Maintenance problems arise with older equipment when parts and services are difficult to obtain. Similarly increases in the costs of utilities are reflected in escalating costs for operating HVAC equipment.

5.9.1 Building design and upgrading environmental equipment. Upgrading to increase capacity often requires additional building space for ductwork, piping, and equipment. Replacement equipment can also have different space requirements. The building may not have the amount and type of space required without a costly construction effort. This is a common condition in older structures, built before the provision of environmental conditioning was routine. Newer buildings, with environmental control systems, have space allocated for HVAC equipment. A good design includes provisions for future changes in mission requirements and the associated environmental control requirements. The availability and type of building space will greatly influence new equipment selection.

5.9.2 Equipment selection. After considering available building space there are many other factors influencing equipment selection. Different environmental control methods may be necessary to handle new heating and cooling loads. The application of these new methods can affect requirements for power and other utilities. The current availability and cost of fuel is an influencing factor. Improvements in current technology call for new approaches in upgrade planning.

a. Automation is usually adopted to improve system efficiency and to reduce operating costs and energy consumption. Automated control will not, however, change the performance of worn out and poorly maintained HVAC equipment. Neither will it provide much improvement over properly selected, adjusted, and maintained controls of the conventional type, which can also provide automatic control. Also, older buildings are provided with pneumatic control networks. The replacement of pneumatic control with a digital system may be costly. A phased replacement of pneumatic control networks, as they wear out, can be feasible by spreading costs over a period of time.

b. Equipment-upgrading efforts provide an excellent opportunity to incorporate energy conservation methods into the environmental control system. Upgrade planners and designers should consider applications of solar energy and heat recovery methods. Significant life-cycle cost reductions and reduced fuel consumption may be achievable.

c. When some components of the original system are retained in a retrofit upgrading, new equipment must be compatible with them. Any new equipment should also meet the recommendations for systems integration contained in all volumes of this handbook. Finally, upgrading equipment should be selected on the basis of its economic operation, maintainability, and demonstrated reliability, as well as being state-of-the-art.

5.10 EMI/EMC/EMP considerations. Refer to volume II of this handbook.

5.11 Transient voltage protection. Refer to volume II of this handbook.

5.12 Grounding, bonding, and shielding. Refer to volume II of this handbook.

5.13 TEMPEST requirements (general). TEMPEST requirements will not be addressed in MIL-HDBK-411B. The information contained in the handbook (MIL-HDBK-411B) should be supplemented with guidance contained in NTISSI-NO. 5203 and MIL-HDBK-232 for power and environmental control on TEMPEST facilities.

NOTE: To determine if NTISSI-NO. 5203 guidelines are applicable, refer to NACSI 5004.

5.14 Fixed-facility design criteria. This section addresses the special considerations of site and building architecture and design, types of construction, and materials used to provide a fixed facility for DoD communications and data processing operations. The guidance presented here is directed toward the construction of new facilities, but should be judiciously applied to retrofit and expansion efforts. The primary purpose of site or facility design is to provide an operating environment which maximizes the reliability, survivability, and long-term economy of the mission equipment systems. Of paramount importance is the protection of mission equipment against failure and damage due to the electrical power, GBS, and environmental control systems. The protection of power-sensitive devices against electrical transients is given special attention in Volume II. HVAC systems should be selected on the basis of their capability to provide quality support over the life of the facility.

5.14.1 Standard floor plan. Selected communications and data processing systems employed within the DoD have a need for the standardized physical arrangements of mission equipment. The justification for these standard floor plans is generally to facilitate installation of common equipment at the various terminal locations, maintain fixed network operating and maintenance procedures, and simplify indoctrination and training of newly arrived personnel. Just because mission equipment must be configured in accordance with a standard plan, however, does not mean that the supporting buildings and electrical/environmental control systems must also be standardized. Every geographical location presents unique conditions that must be taken into account when designing structures and supporting systems. These conditions should be identified in site survey data, as discussed in

5.3. Types of construction, building materials, and supporting systems must be chosen on the basis of how the will perform in the environment to which they will be subjected. Life cycle costs of a DoD installation should be studied in terms of established mission reliability factors (99.99+), survivability, energy consumption, and environmental impact.

5.14.2 Inside environment. The design of a DoD communications or data processing facility must provide access and space for both known and anticipated future mission and supporting equipment. These facilities have unique access requirements for power and signal cabling, as well as environmental control networks of ductwork, piping, and control circuitry. Whenever possible, water and sewage pipes, or other potential sources of damage, should not be routed through or directly above sensitive electronic equipment spaces. Improper planning that results in last minute “quick fixes” and "add ons” often creates Interference problems among the various mission and support systems being operated.

5.14.2.1 Ducts for communications. One of the most important communications concerns in the design of a new installation is that usable cable trays, trenches, or ducts with adequate growth potential, are addressed durin basic building design. The number of building entry points, which are usually minimized and through conduit, should be in accordance with military department rules. Building and room entry points should be sealed against the infiltration of unconditioned air into controlled spaces, especially to critical areas housing computers or other sensitive electronic devices. The layout of cable trenches and ducts should be based upon the pre-established floor plans of terminating mission equipment. When concrete floors are provided in electronic equipment rooms, cable trenches should be of the correct configuration and size to meet reasonable growth, as well as meeting initial design requirements. The communications distribution network should be designed in conjunction with the station power and environmental control systems to minimize mutual interference. The incorporation of equipotential planes conforming to MIL-HDBK-419 are specified by the DCA for all DCS concrete-slab equipment room floors. The inclusion of equipotential planes in concrete-slab floors of other DoD electronic facilities should be in accordance with recommendations contained in Volume II and appropriate military department guidelines. Similarly, bonding of cable trays (normally to building steel) should also be accomplished in accordance with (IAW) military department practices. See Volume II, paragraph 5.5.6.

5.14.2.2 Raised floor considerations. Raised floors, which are sometimes called access floors, are commonly installed in computer rooms to facilitate the distribution of cabling. The incorporation of equipotential planes and the bonding of raised floor supports and panels should be accomplished according to recommendations contained in Volume II and military department rules. The area under raised floors is sometimes used as a plenum for the distribution of conditioned air, if space permits. This practice has the advantage of simplifying access to equipment cabinetry. However, special care must be taken to ensure that the integrity of the under-floor space is preserved, to preclude raw untempered air from entering directly into electronic equipment cabinets before it is tempered with room air. Entrances for cable and other services must be kept sealed against the entry of under-floor untempered air. It should be noted that additional energy to operate blowers or fans is generally required to operate an under-floor air distribution system, as opposed to an above-floor system, due to acceleration/deceleration losses. If water pipes are also present in the area under the raised floor, leakage monitoring devices with suitable alarms should be installed.

5.14.2.3 Ducts for power distribution. The power distribution network should be designed and installed in accordance with National Electric Code (NEC) standards. Necessary physical separation between conductors, both power and signal, should be designed into distribution systems to prevent interference. Where physical separation is not possible, shielding should be employed. More detailed information on power system distribution 1s contained in Volume II.

5.14.2.4 Utility distribution. Ductwork and pipe systems for the distribution of air and water are normally installed in accordance with respective military department building criteria and local building codes. While the DoD is not obligated to conform to local building codes, local standards which are higher than those of the DoD are usually adhered to. Building criteria and codes are concerned with personal health and safety, building protection, and the conservation of energy. Of special concerns are duct insulation to reduce unwanted heat gains and losses, control of smoke and fumes, and minimizing noise and vibration. It is becoming more conmnon to adapt architectural designs to accommodate building utility systems, rather than “fitting” utilities into available space. In DoD facilities, the security aspects of HVAC and other utility systems must be addressed in the building design effort. Also, the protection of sensitive electronic equipment from transients and other interference caused by HVAC systems is part of the GBS task.

5.14.3 Outside environment. The building design for a DoD installation should provide a cosmetically acceptable structure that will support mission equipment and personnel in a reliable and economical manner. As indicated in section 5.3, data on the facility location gathered during the site survey should strongly influence building design. This section addresses certain features of DoD facilities that make them unique from typical civilian industrial installations.

5.14.3.1 Normal construction. Basic construction criteria are contained in construction criteria documents of the military departments. Permanent DoD buildings should be designed for a life cycle of 25 years. Semipermanent buildings have a life cycle of 5 to 25 years. For a DoD Comunications or data processing facility, normal construction may be defined as construction without special hardening or shock-mounting considerations. Most cormnunications and ADP buildings have a limited number of doors and windows because of security requirements. The exterior walls should normally be concrete (cast-in-place or precast) or masonry; however, steel frame construction with a suitable outer shell of masonry or metal panels should also be considered. Multi-storied buildings are usually of steel frame construction. Steel frame construction can be less expensive than solid concrete or masonry structures, and building steel can be utilized for GBS purposes. This can be a major advantage in electronic facilities. Roof construction should be of concrete, steel, or other noncombustible materials. Peritlanent interior walls should be concrete or masonry. Nonpermanent walls should be of fireproof materials, in accordance with appropriate military department standards. Flooring should be of concrete slab or metal panels. The design of walls and floors should provide for the distribution of power and signal cabling and utilities. The use of wood for framing and flooring in electronic facilities is not recommended because of fire danger. Finishes, hardware, and other appearance items should be in conformance with military department guidelines.

5.14.3.2 Hardened construction. The amount of special protection a facility receives through hardening is determined by the survivability criteria of the facility and the threat assessment for the geographical area. This section addresses hardening against physical damage caused by sabotage, blast and thermal effects, civil strife, severe weather conditions, and similar disturbances. Hardening against electronic damage from EMP/HEMP and other transients is addressed in other sections of this handbook. Hardening a building to withstand the blast pressures from explosions involves increasing the strength of structural elements (walls, foundations, beams, columns, roofs, etc.). A number of computer programs concerning architectural design and structural mechanics are available. The hardening of DoD electronic facilities through special construction features, can impact the environmental contro systems supporting those facilities.

a. The use of reinforced construction techniques to increase structural strength against predicted blast pressures can also improve insulating values and building tightness against heat gains and losses. Core areas of concrete floors, walls and ceilings can be filled with insulating materials to increase R-values. Increased use of concrete also provides excellent opportunities for application of thermal storage energy-conservation techniques. For example, large concentrations of concrete or masonry can be used as solar energy storage mass in active and passive collection systems. Reinforcing steel can be incorporated into building grounding and shielding schemes. It should be noted that because of the vulnerability of solar collectors to blast effects, their use should be carefully evaluated in terms of cost of installation and potential savings of energy.

b. Earth-sheltered structures have some portions of their exterior walls below ground. By definition, a building with a climate-controlled basement is an earth-sheltered structure. The design of an earth-sheltered structure is not as greatly influenced by the climatic and geographical features as an above ground site. Data gathered during the site survey is more important to the design of these structures than conventional buildings. Earth sheltering is achieved by excavation, tunnellng, or earth berming. The advantages that earth-sheltered structures offer to the design and operation of environmental control systems varies with geographical location, and types and sizes of buildings. The below-grade temperature of the earth will determine whether heat flow will be positive (from building to earth) or negative (from earth to building). Solar thermal heat gain is, of course, not a factor. effects of infiltration on heating loads is reduced by earth sheltering, primarily in northern areas. For electronic facilities in northern areas, which require year-round cooling because of high-heat-generating equipment, some energy savings can be realized if the controlled spaces are located near earth-sheltered walls. As the size of buildings increases, the interior space should be divided into environmental control areas, called mechanical zones. Those zones with the largest energy requirement should be placed *near* building perimeters. Large buildings with varied mechanical zones are excellent candidates for heat recovery systems. The advantages of reduced energy costs of earth-sheltered construction must be evaluated in terms of facility life cycle costs. Other significant considerations are the costs of excavation, earthwork, reinforcing to support earth weight, protection against moisture, ventilation systems, and life safety (see appendix E of this volume).

5.14.3.3 Shock mount isolation. Selected DoD equipment and structures are shock mounted as part of the hardening scheme to provide protection against blast damage. Sensitive electronic devices require shock mount isolation to enhance survivability. Similarly, entire structures, such as command posts and communications centers, are sometimes provided with special isolation devices in foundation support. The use of isolation mountings with heavy equipment, such as power generators and compressors, also reduces the effects of the noise and vibration they produce in normal operation. Reducing the effects of noise and vibration on personnel, as well as equipment, is a vital part of maintaining an acceptable environment at survivable installations which may be required to sustain operations in a physically secured condition.

5.15 Facility integration. The purpose of facility integration is to design, install, and operate the many systems that comprise a DoD facility so that their performances are not counterproductive. The output of an individual system should not jeopardize the performance, protection, and reliability of other systems.

5.15.1 Power and signal line integration. A major factor which must be considered when designing a facility is the integration of power and signal lines. Improper design and installation practices may result in impaired operation of sensitive electronic equipment due to the electromagnetic effects of noise generated by electrical power circuits. Signal lines include those lines used for communication circuits, data processing systems, alarm circuits, environmental control systems, and monitor circuits.

5.15.2 Environmental control system integration. The environmental control system of a facility is composed of various types of HVAC equipment. Systems supporting large installations with closely controlled indoor environments can be very complex. In a properly designed system, HVAC equipment operates in an integrated manner, so that the output of individual devices will not interfere with or be counter to the performance of the others. Counter-productive performance results in incorrect indoor conditions and wasted energy. For example, excessive cooling may require the addition of heat or humidity to a space to maintain design conditions. Similarly, excessive amounts of raw outdoor ventilation air requires energy for conditioning. Both system control and energy-management program functions should be responsive to reductions of HVAC equipment performance. In addition to poor equipment performance, incorrect adjustment or tampering with controls, and degrading the integrity of controlled spaces create problems. Tampering with control settings has the unwanted effects of changing other parameters and the conditions in other spaces. Operating unauthorized equipment and unnecessary opening of doors and windows can cause serious deviations from design conditions.

5.15.2.1 Regulating fluid flow. Regulating the proportional flow of air and water within distribution ducts and piping is called balancing. Regulating flow rates at terminal devices (registers, louvers, inlets, and outlets) is called adjusting. Balancing is normally accomplished as a final installation procedure, before turnover to the user. An environmental control system should be designed to include the necessary regulating devices to perform periodic balancing and adjusting. Maintenance personnel require complete and accurate documentation for all HVAC equipment, as well as detailed instructions for balancing and adjusting functions. Testing is accomplished with anemometers (air speed), manometers (air pressure), tachometers (rotational speed), and flow meters (liquid flow rate).

5.15.2.2 Testing control devices. All control devices, both analog and digital, require periodic testing to ensure correct operation. Sensors should also be tested for accuracy, and calibrated or replaced as required. Instrumentation includes precision thermometers and hygrometers, calibration standards, and software for evaluating the accuracy operation of digital devices.

5.15.2.3 Noise and vibration testing. Equipment such as power generators, refrigeration compressors, and large motors are potential sources of noise and vibration. Periodic testing of these devices should be part of monitoring and control programs. Test measurements for noise are made with sound level meters and sound analyzers. Specially designed meters and analyzers are used for vibration measurements. Noise and vibration measurement and analysis software is available for small computer (PC or microprocessor) applications.

5.15.3 Integrated control of mission support elements. Several mission support functions for DoD facilities lend themselves to assignment to an integrated control console or panel. For example, fire detectors, HVAC, and emergency generator indicators, security light control, CCTV (monitoring building security and operation of control valves, etc.), and power quality monitors are all likely candidates for integrated control. Integrated control not only saves manpower but also decreases reaction time during multiple emergencies.

5.16 Future environmental control trends which may impact DoD communications and data processing facilities. The continuing escalation of energy costs is driving advances in HVAC management and technology. The energy being consumed by environmental control systems is becoming a matter of everyday installation management. Energy management and life cycle cost analysis programs are finding common application, especially in large installations. New equipment and systems are being developed to operate more efficiently. This pursuit of more efficient operation also stimulates research of new materials and technologies. The greatest improvements in environmental control are probably reflected in new monitoring and control devices that employ microprocessors. Precise control can preclude the unnecessary and counterproductive operation of heating, cooling, ventilation, and humidity equipment. State-of-the-art equipment and systems should be used in new and upgraded fixed facilities, if their choice is in the best long-terra interest of the Government. Designers and engineers must, however, be careful not to confuse state-of-the-art with short-term fads. It should be recognized that many DoD electronic facilities, operating 24-hours per day with relatively constant heating and cooling loads, may not be candidates for some energy saving techniques. At these locations, solar and thermal loads are a small part of the total energy load. Also, fenestration is normally minimal, for security reasons.

5.16.1 Energy management. The cost of providing a closely controlled climate in a DoD electronics installation is a major budget item. Included in the design of state-of-the-art environmental control systems are programs for the continuous management of energy consumption and the analysis of life cycle costs. These programs, which are usually automated, provide an instant picture of both current and projected energy costs. The information received can be used to verify the performance of installed systems and to indicate the need for replacement and upgrade. Paragraph 5.8 contains more detailed information on energy management programs.

5.16.2 Computers and environmental control. The speed and accuracy of computerized devices are improving both the design and operation of environmental control systems. An expanding selection of supporting software is being developed to help with the choice and configuration of HVAC equipment and materials. The calculation of heating and cooling loads, which is a major task common to all building designs, can be greatly facilitated with the computer. Programs for designing duct and piping networks can simplify and improve engineering efforts. Similarly, the selection of component boilers, fans, coils, pumps, and related equipment can be computer aided. Through computer modeling, the use of alternative HVAC equipment can be evaluated in terms of anticipated life cycle costs. Use of available HVAC software should be made in the selection of environmental control systems for DoD facilities. It is anticipated that the prohibitions against the use of automated environmental control within the DoD will be removed when maintainability and reliability are sufficiently improved.

5.16.3 New technologies. Reducing the consumption of nonrenewable fuels and increasing the use of renewable resources should continue to be the primary goals of developing HVAC technology. Fuel burning furnaces and boilers are being made more efficient by such innovations as pulsed burning, exhaust heat recovery, and improved materials. Increased use of thermal storage will reduce the use of energy resources for both heating and cooling. Available heat energy collected from the sun and recovered from industrial processes will be stored in water and masonry heat sinks and substances with special properties. Building will be designed and constructed to make them adaptive to the natural conditions and features of their geographical location. The importance of heat mass and fenestration is being given more attention in building construction, Substances which store and release large amounts of heat during chemical reactions or changes in physical state will find increasing application in HVAC. Meeting the increasing demand for cooling will be aided with the use of supplemental systems, such as ice bank storage, In an ice bank storage system, ice is made at night, when the cooling demand is lowest. This stored ice is then used during peak load hours to supplement refrigeration equipment. Ice bank storage permits the installation of smaller refrigerant equipment and reduces operating costs. Selective use of fenestration will increase daylighting and reduce the heat generated by artificial lighting, as well as lowering costs. Figure 36 shows one consulting engineer's solution to a large, energy efficient, integrated system that lends itself to automated control. In the future of automated control, specialized integrated circuits (ICs) will be developed to improve computer to electromechanical actuator functions. Fiber optic systems are being used increasingly for building control links. In addition to digital control functions, intercoms can be integrated with the fiber optic system to provide analog maintenance information or to provide audible confirmation of equipment start up and shut down. Fiber optic systems exhibit definite advantages. They are difficult to tap without detection, and they are relatively invulnerable to EMI, EMP, and atmospheric disturbances. In addition, conduit is not required by building codes but may be necessary in certain environments for radiation hardness and abrasion resistance. Figure 37 shows a fiber-optic-connected control system which uses bidirectional transmission to improve reliability. In this configuration, a single repeater failure or a single cut of both fibers will not disrupt the control system.

5.16.4 New materials. New and improved construction and HVAC materials are being developed. Stronger and lighter materials permit greater efficiency and innovation in architectural design. Improved insulating materials and tighter buildings reduce unwanted heat gains and losses, but an increased potential of reduced indoor air quality. Fiber optic devices will distribute natural light to interior building spaces, reducing the demand for energy-consuming and heat-producing artificial lighting. Superconducting substances now being researched will revolutionize power distribution and control circuitry.

5.14.5 New equipment. HVAC equipment will continue to be improved, as efforts to reduce fuel consumption are pursued. New equipment is smaller, cleaner, and more efficient. Use of solar energy for heating and cooling will be expanded. Heat recovery applications will grow, as improved heat exchangers are developed. Continued public concern over pollution will drive the development of improved ventilation and filtration equipment. Finally, the use of computerized devices for the design and operation of environmental control systems will become commonplace.

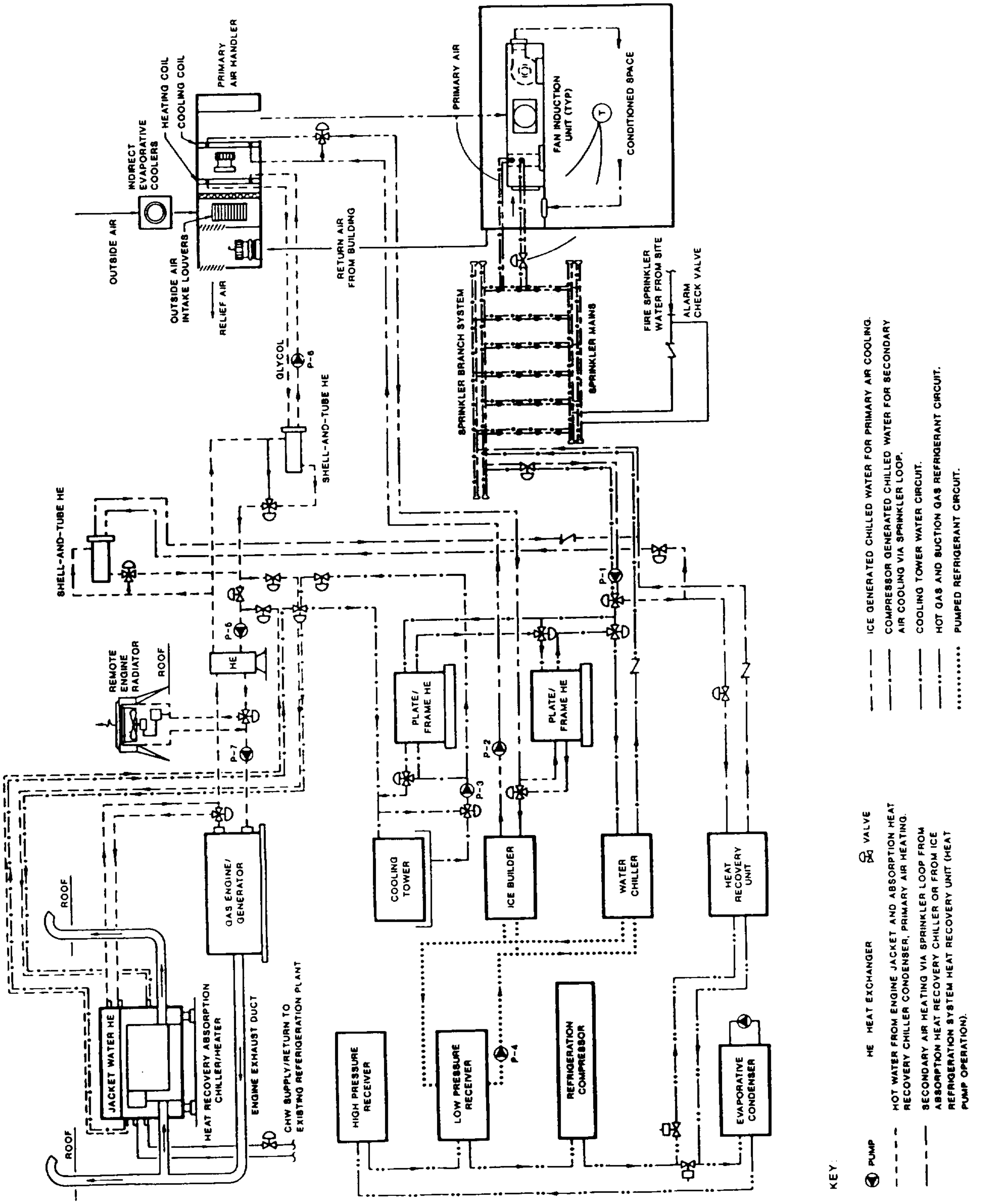


FIGURE 36. Integrated ice storage/sprinkler/cogeneration/HVAC system diagram.

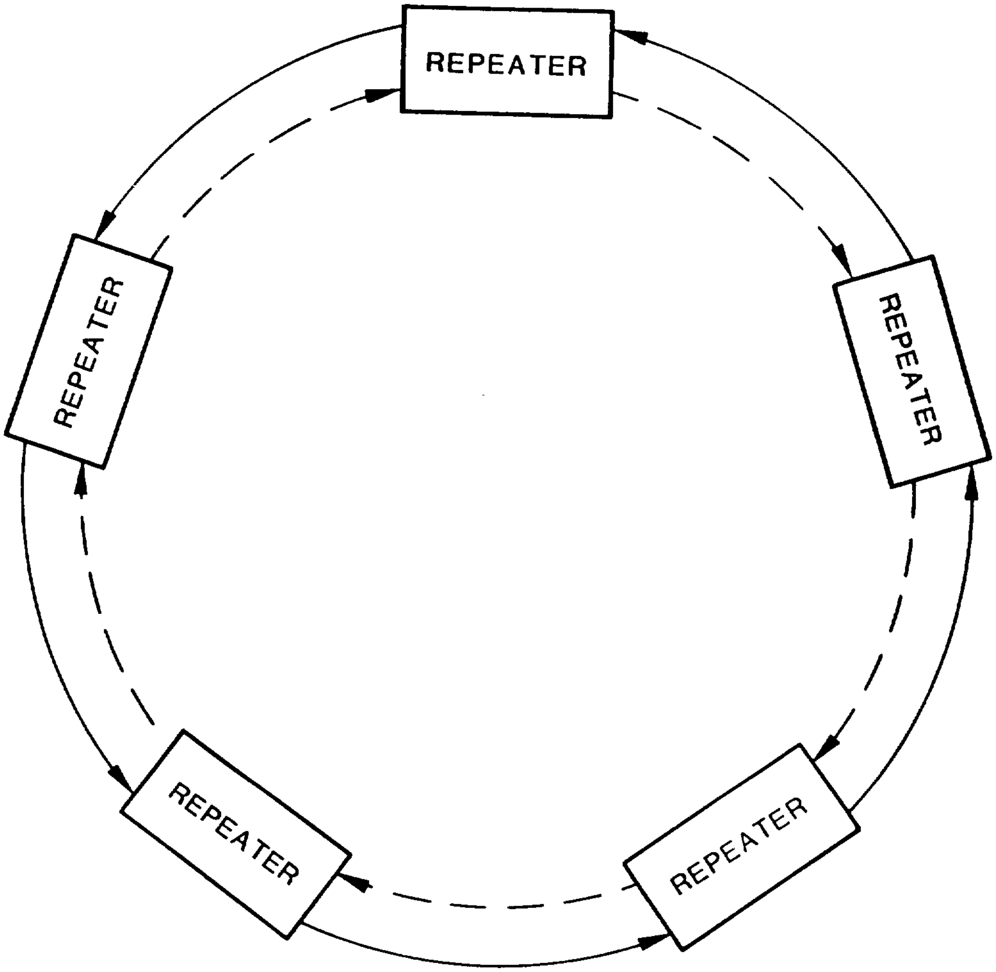


FIGURE 37. Redundant fiber optic loop transmission system.

6. NOTES

6.1 Intended use. The purpose of this handbook is to provide basic guidance to managers and engineers of the military departments and agencies in the design and installation of environmental control systems at DoD fixed-communications and related automatic data-processing facilities. The subject matter included in the text is intended to make the designer and manager of a communications or data processing facility better able to interface with HVAC designers and providers.

6.2 Issue of DoDISS. When this handbook is used in acquisition, the applicable issue of the DoDISS must be cited in the solicitation (see 2.1.1, and 2.2).

6.3 Subject term (key word) listing.

absorption
adsorption
air circulation
air conditioning
air filters
air flow
candelas
comfort
condensation
condenser
conduction
convection
coolers
cooling
cooling coil
cooling load
cooling rate
cooling systems
dehumidifiers
ducts
environmental control
environmental engineering
environments
exhaust systems
fenestration
fluid flow
heating
heating load
heat gain
heat loss
heat transfer
heat transfer coefficient
humidifiers

humidity control
illumination
lighting
lumens
luminous flux
luminous intensity
refrigerating
temperature
temperature control
temperature distribution
variable air volume
ventilation
venting
vents
visual comfort
waste disposal
water supply
water treatment

6.4 Changes from previous issue. This revision correlates to the previous issue in concept only. The content has been subjected to extensive change and reorganization to reflect emerging technology. Asterisks or vertical lines are not used in this revision to identify changes with respect to the previous issue due to the extensiveness of the changes.

Custodians
Army - SC
Navy - EC
Air Force - 90

Review activities
Army - CR,CE
Navy - YD,MC
Air Force - 50
DoD - DC,KP

Preparing activity
Army - SC

(Project SLHC-4112)

ALTERNATING CURRENT (ac) THEORY, POWER USAGE DATA COLLECTION, AND USEFUL CONVERSIONS

10. Scope. This appendix provides a brief review of alternating current (ac) theory as well as a method to manually estimate ac power consumption and useful electrical /electronic/metric conversion tables. This appendix is to be used as a refresher only. For exact applications, a comprehensive text or individual military department technical publications should be consulted.

20. Applicable documents. This section is not applicable to this appendix.

30. Definitions. See paragraph 3.1 of this handbook.

40. Review of alternating current (ac) theory.

40.1 Elements. The ultimate particles of an element are called atoms. An atom consists of a small, relatively heavy nucleus with a number of lighter electrons circling it. The nucleus in turn is composed of protons and neutrons which, like electrons, are elementary particles that cannot be subdivided further.

40.2 Electric charge. Electric charge is a basic property of protons (positive) and electrons (negative). Charges of the same sign repel each other; charges of opposite sign attract each other. The number of protons in the nucleus of an atom normally equals the number of electrons around it; therefore, the atom as a whole is electrically neutral.

40.3 Electric current. The unit of electric charge is the coulomb (C). The charge on the proton is ^{+}e, and that on the electron is -e. A flow of charge from one location to another constitutes an electric current. A conductor is a substance through which charge can flow easily, and an insulator is one through which charge can flow only with great difficulty. Metals, many liquids, and gases whose molecules are electrically neutral are insulators. A number of substances, called semiconductors, are intermediate in their ability to conduct charge. Electric currents in metals consist of electron flow; such currents are assumed to occur in the direction opposite to that of electron movement. Since a positive charge moving in one direction is essentially equivalent to a negative charge moving in the opposite direction, this assumption makes little practical difference. Both positive and negative charges move when a current is present in a liquid or gaseous conductor. When an amount of charge (Q) passes a given point in a conductor in the time interval (t), the current (I) in the conductor is:

$$I = \frac{Q}{t}$$

$$\text{or current} = \frac{\text{charge}}{\text{time interval}}$$

The unit of electric current is the ampere (A), where:

$$1 \text{ ampere} = \frac{1 \text{ Coulomb}}{\text{second}}$$

Essentially, ac circuit analysis is performed in much the same manner as dc circuit analysis. The notation to describe dc current and voltage, network theorems, and Kirchhoff's laws still apply. However, where simple algebra provides most solutions for dc circuits, higher levels of mathematics are required to find exact solutions to ac circuitry. The most sophisticated mathematics is required for ac study because ac currents and voltages vary with time, and this means additional circuit parameters besides resistance must be considered. When the driving voltage or current sources are fixed in magnitude and polarity, as in dc circuits, the only opposition offered to the flow of current is due to the circuit resistance (R).

40.4 Ac circuit characteristics. When the voltage source and/or current vary with time, even a short section of wire reacts in some degree to the following:

a. An opposition to the flow of current (resistance, R)

b. An opposition to the change in current (inductance, L)

c. An opposition to the change in voltage (capacitance, C)

40.5 Development of waveforms. A voltage or current plotted versus time is called a waveform. Figure A-Ta, for example, is a plot of a constant dc voltage (e) versus time (t). If the dc polarity is reversed, we have the result shown in A-lb.

a. If a waveform reverses polarity periodically, it is referred to as an alternating current or voltage. If the switch in figure A-2a is moved periodically between positions A and B, the waveform in figure A-2b would result. Several of the commonly generated waveforms are illustrated in figure A-3. Parameters that are of particular interest when studying periodic waveforms are:

(1) Positive peak amplitude

(2) Negative peak amplitude

(3) Peak-to-peak amplitude

(4) Period

(5) Frequency

(6) Average value (dc component)

(T) Root-mean-square (rms) value

b. To understand the significance of these parameters, consider the example shown in figure A-4. In this illustration, +100 volts is the positive peak amplitude. It is important to realize that the peak positive amplitude of a waveform could be assigned a negative value if the entire waveform is below the zero axis.

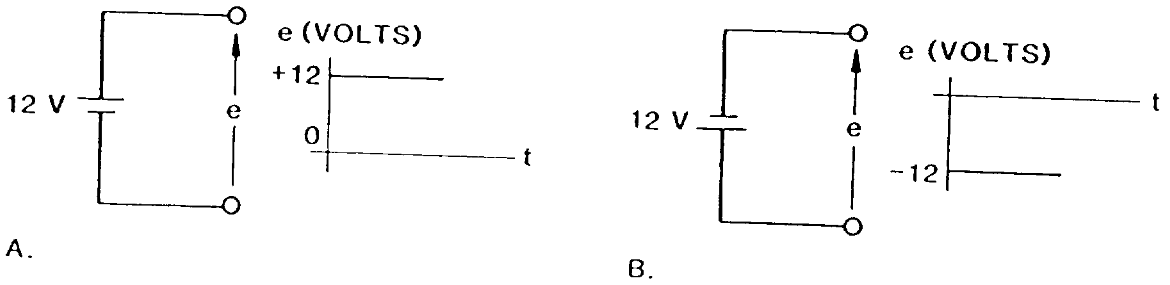


FIGURE A-1. Voltage plotted against time.

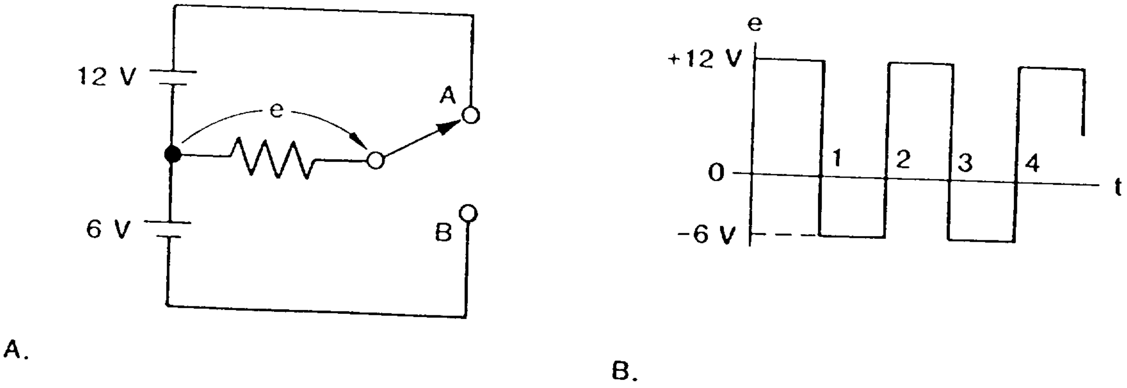


FIGURE A-2. Results of switched dc

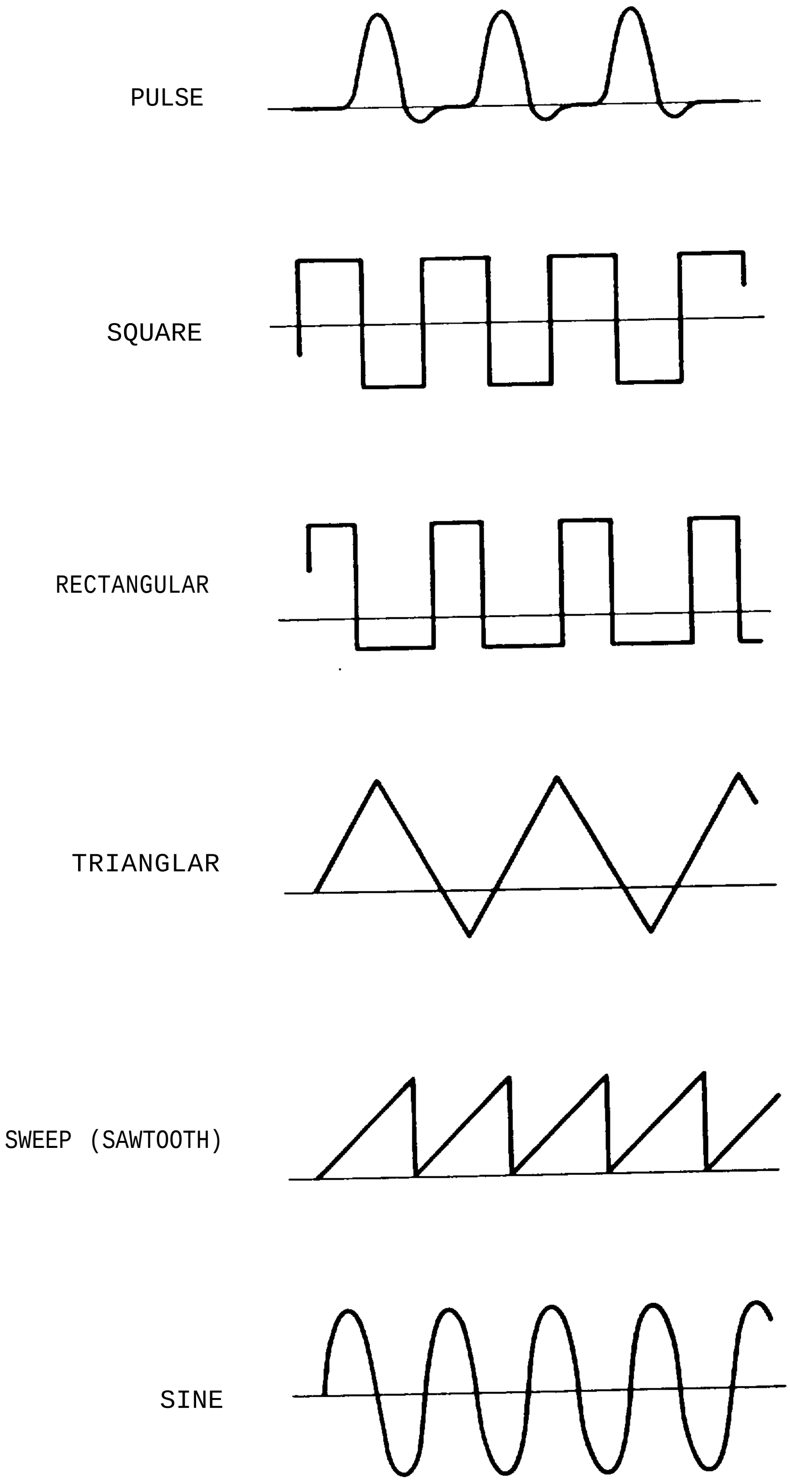


FIGURE A-3. Commonly generated waveforms.

c. The negative peak amplitude in figure A-4 is -120 volts. If all of a waveform lies above the zero axis the peak negative value will be assigned a positive number.

d. The peak-to-peak amplitude is the absolute value of the amplitude between the positive and negative peak amplitudes. Thus for figure A-4, the peak-to-peak (abbreviated p-p or pk-pk) amplitude is 220 volts.

e. The period (T) of a waveform is the length of time it takes to repeat itself. Thus in figure A-4 the period is T = 10 sec.

f. The frequency (f) represents the number of times the waveform repeats itself in a given time interval . If the time interval is equal to the period, the waveform has completed one cycle. Frequency and period are reciprocal quantities expressed by:

$$f = \frac{1}{T}$$

$$\text{and,} \quad T = \frac{1}{f}$$

The hertz (Hz) is the international unit used to therefore:

$$1 \text{ Hz} = \frac{1 \text{ cycle}}{\text{sec}}$$

With the adoption of Hz as the international unit, the expressions 10,000 cycles/see or 10 kilocycles/see (l0 kc/s), become 10,000 Hertz or 10 kilohertz (10 kHz).

The average value of some periodic waveform is its average value as determined over a time interval equal to the period T. The average value is the dc component of a waveform, and it represents what a dc voltmeter would read if it were driven by a voltage waveform. To find the average value of any function, say y = f(x), over some interval, as shown in figure A-5, it is necessary first to determine the area bounded by the curve (shaded area) during this interval and then to divide this area by the length of the interval. This yields the average value. In figure A-5, some of the area is positive and some is negative. To obtain the net area, subtract the negative area from the positive. If the negative area exceeds the positive area, a negative average value will result. Mathematically, the average value of a waveform is expressed as an integral:

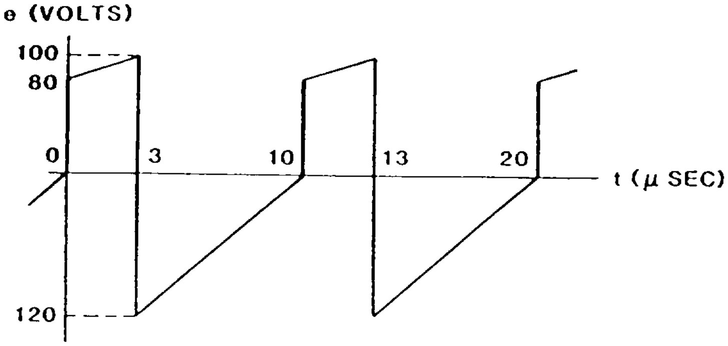


FIGURE A-4. Peak voltage generation.

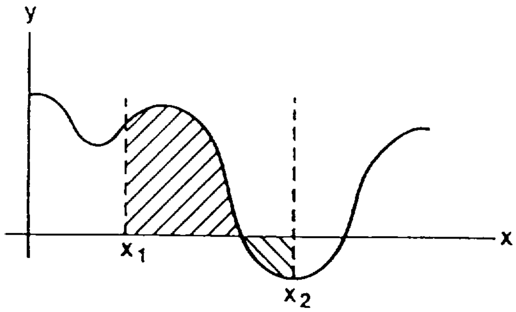


FIGURE A-5. Average waveform value.

$$\text{Average value} = \frac{1}{t_2-t_1}\int_{t_1}^{t_2} f(t)dt$$

where $t_2 - t_1$ is the time interval over which we seek the average value, usually equal to the period, and

$$f(t)dt$$

is a mathematical symbol used to designate the area under case a plot of some f(t), meaning function of time) over an interval $t_2 - t_1$. A simple interpretation of the integral is:

$$\text{Average value} = \frac{\text{the net area between the waveform and the time (t) axis during a given time interval}}{\text{the given time interval}}$$

h. The root-mean-square or effective value of a waveform represents developed power. For example, if some periodic voltage waveform is impressed on a resistor, the resistor will dissipate heat. This heat dissipation will occur even if the average value of voltage (or current) is zero. In this case, the direction of current flow does not matter - current flow through the resistor causes energy loss. By definition, the effective or rms value of a voltage (or current) waveform is that value which develops as much average power in the resistor and an equivalent dc voltage. To determine the rms voltage value of a waveform, the instantaneous power at any moment in time is given by:

$$P = \frac{e^2}{R},$$

where e is the instantaneous voltage across the resistor R.

i. There are two kinds of power we are usually interested in - instantaneous power (p) and average power (P). The instantaneous power for any waveform of voltage or corresponding waveform of current is given by:

$P = ei$
P = instantaneous power
e = instantaneous voltage
i = instantaneous current

The current and voltage waveforms need not be the same. In fact, most ac circuits display leading or lagging currents and voltages. To determine average power in any device, and with e and i waveforms, generate the p curve by the P = ei equation, and then determine the average value of the p curve in a manner similar to the average voltage or current method discussed above. For a waveform of period T,

$$P = \frac{\text{area under the } p \text{ curve during the interval } T}{T}$$

The average and rms values of a waveform will not be the same, therefore, rms rather than average voltage or current values is used when computing power.

40.6 Power generation. The most common form of electric power is produced by generators which convert mechanical energy to electrical energy. Most of these generators develop an alternating voltage (and current) with a waveform that closely resembles figure A-6. Because this type of waveform is based on a trigonometric function called the sine, it is referred to as a sine wave or a sinusoid.

40.7 Voltage. In order to make current flow through a conductor, an electrical pressure is required to separate the electrons and protons. This electrical pressure (also called the electromotive force or the potential difference) is known as voltage, and the basic unit of measure is the volt.

40.8 Constant potential systems. The most common type of system for electrical distribution is the constant potential type where the voltage is kept as constant as possible and the current varies-with variations in-the load. This system is further subdivided into alternating and direct current.

40.9 Alternating current (ac) systems. Current in alternating current systems first flows In one direction around a loop of conductive material, then reverses and flows in the other direction at regular recurring intervals. Most power systems are of the alternating current type. To understand how this type of current is produced, a simple two-pole generator is described. Basically, this generator consists of a north and south magnetic pole and a loop of wire fixed so it can rotate between the poles as shown in figure A-7. As the loop rotates between the poles, a current is induced which flows in one direction through the first 180 degrees. The induction of current occurs when the loop cuts the magnetic lines of force flowing from the north to the south pole. When the loop reaches the 90 degree point, the maximum number of lines are being cut and the induced current is at a maximum. When the loop reaches the 180 degree point, it is no longer cutting any lines of force and the current is zero. One complete revolution of the loop constitutes one cycle because the current has gone from zero to maximum value twice as shown in figure A-7.

40.10 Single-phase power. The current produced by this generator is single-phase because only one source of induced current (one loop or coil) is used between the poles. An electrical system can be identified by the number of wires and the voltage between the wires. For example, figure A-8 shows a single-phase, two-wire, 120-volt system. The notation for this system is 1O-2W-12OV. A single phase, three-wire, 120- /240-volt system would be shown as 1O-3W-120/24OV.

TABLE A-VIII. Units, constants, frequency spectrums and conversion factors - Continued.

C. Conversion factors for units of lcngth.

Multiply number of by to obtain number of	Angstroms	Nanometers	Micrometers	Millimeters	Centimeters	Meters	Kilometers	Mils	Inches	Feet	Miles
Angstroms	1	10	10^{4}	10^{7}	10^{8}	10^{10}	10^{13}	2.540 x 10^{5}	2.540 x 10^{8}	3.048 x 10^{9}	1.609 x 10^{13}
Nanometers	10^{-1}	1	10^{3}	10^{6}	10^{7}	10^{9}	10^{12}	2.540 x 10^{4}	2.540 x 10^{7}	3.048 x 10^{8}	1.609 x 10^{12}
Micrometers (Microns)	10^{-4}	10^{-3}	1	10^{3}	10^{4}	10^{6}	10^{9}	2.340 x 10	2.540 x 10^{4}	3.048 x 10^{5}	1609 x 10^{9}
Millimeters	10^{-7}	10^{-6}	10^{-3}	1	10	10^{3}	10^{6}	2.540 x 10^{-2}	2.540 x 10	3.048 x 10^{2}	1609 x 10^{6}
Centimeters	10^{-8}	10^{-7}	10^{-4}	10^{-1}	1	10^{2}	10^{5}	2.540 x 10^{-3}	2.540	3.048 x 10	1.609
Meters	10^{-10}	10^{-9}	10^{-6}	10^{-3}	10^{-2}	1	10^{3}	2.540 x 10^{-5}	2.540 x 10^{-2}	3.048 x 10^{-1}	1.609
Kilometers	10^{-13}	10^{-12}	10^{-9}	10^{-6}	10^{-5}	10^{-3}	1	2.540 x 10^{-8}	2.540 x 10^{-5}	3.048 x 10^{-4}	1.609
Mils	3.937 x 10^{-6}	3.937 x 10^{-5}	3.937 x 10^{-2}	3.937 x 10	3.937 x 10^{2}	3.937 x 10^{4}	3.937 x 10^{7}	1	10^{3}	1.2 x 10^{4}	6.336 x 10^{7}
Inches	3.937 x 10^{-9}	3.937 x 10^{-8}	3.937	3.937 x 10^{-2}	3.937 x 10^{-1}	3.937 x 10	3.93 x 10^{Z}	10-3	1	12	6.336 x 10^{4}
Feet	3.281 x 10^{-10}	3.281 x 10^{-9}	3.281 x 10^{-6}	3.281 x 10^{-3}	3.281 x 10^{-2}	3.281	3.281 x 10^{3}	8.333 x 10^{-5}	8.333 x 10^{-2}	1	5.280 x 10^{3}
Miles	6.214 x 10^{-14}	6.214 x 10^{-13}	6.214 x 10-^{10}	6.214 x 10^{-7}	6.214 x 10^{-6}	6.214 x 10^{-4}	6.214 x 10^{-1}	1.578 x 10^{-8}	1.578 x 10^{-5}	1.894	1

40.11 Two-wire systems (10-2W). In the single-phase, two-wire system (figure A-8), one of the two wires from tne generator is connected to ground and is called the grounded conductor or neutral. The other wire is called the phase conductor. Normally, the voltage difference between these conductors is 120 volts. In this system the current in one conductor equals the current in the other. Facilities that use single-phase current usually have very light electronic and lighting loads.

40.12 Three-wire systems (10-3W). In this system, there are two voltages available which provide the advantage of simultaneously obtaining a high voltage for heavy loads and a lower voltage for lighter loads. Figure A-9 illustrates the three-wire, single-phase system. In this particular wiring arrangement (called a wye), the voltage between the phase conductors is approximately twice the voltage between the neutral and either phase conductor. The current in the neutral (grounded) conductor is equal to the difference between the currents in the phase conductors. When the connected load between the neutral and one phase equals the connected load between the neutral and the other phase, the loads are balanced. Under this condition, the currents in the phase conductors are equal and neutral current flow is zero.

40.13 Three-phase power generation. If three coils (or loops) separated by 120 degrees are used, the current is induced in each one by the poles at a different time with the result shown in figure A-10. Note that the illustration shows a much smoother sequence of impulses than the earlier single-phase illustrations. Single-phase power has not become obsolete by the increased use of the three-phase concept as each type has its own specific application based on the type of load to be served.

As stated before, three-phase power is, in effect, generated by three precisely spaced single-phase coils. This system usually consists of four conductors, although three conductors are sometimes used. Each conductor represents one phase. As the three-phase power is produced in the generator, one of two methods is used to connect the coils for distribution to the load:

The Y (wye) or star connection
The Δ or delta connection

Normally the delta generator connection employs three wires and the wye employs four wires.

b. Three-wire systems (30-3W). Figure A-n shows a three-phase, three-wire system using a delta connection. All three wires are considered phase conductors. Any 1O-2W, 240-volt load may be connected between any two-phase conductors. One of these phases may have a grounded center conductor brought out, if required, to serve a 1O-2W, 120-volt load. provision for a 10-2W, 120-volt load can also be made external to the generator by using a center-tapped transformer.

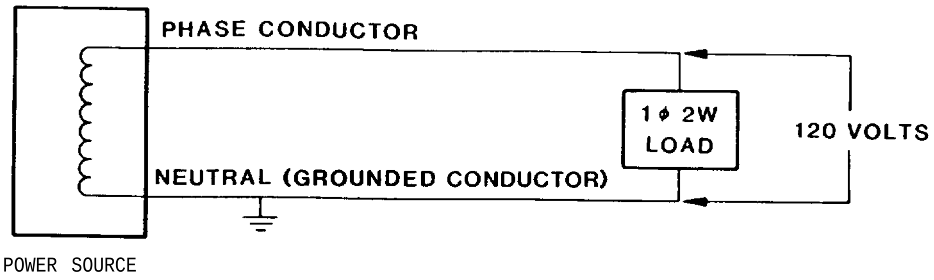


FIGURE A-8. Single-phase ac power.

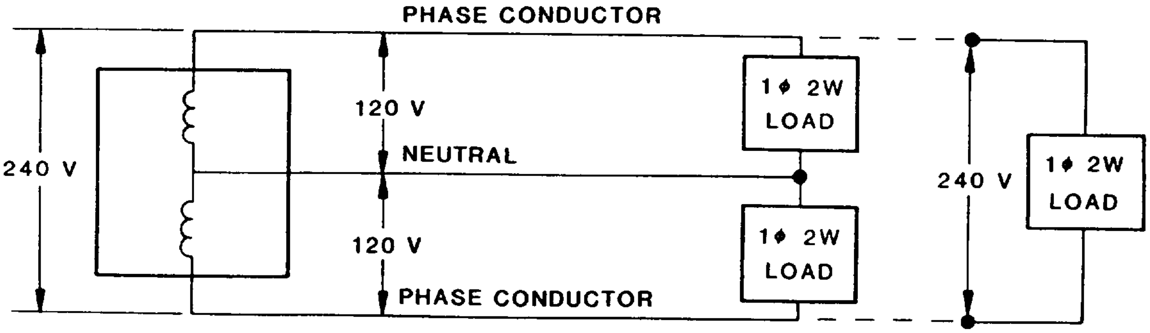


FIGURE A-9. Single-phase, three-wire ac power.

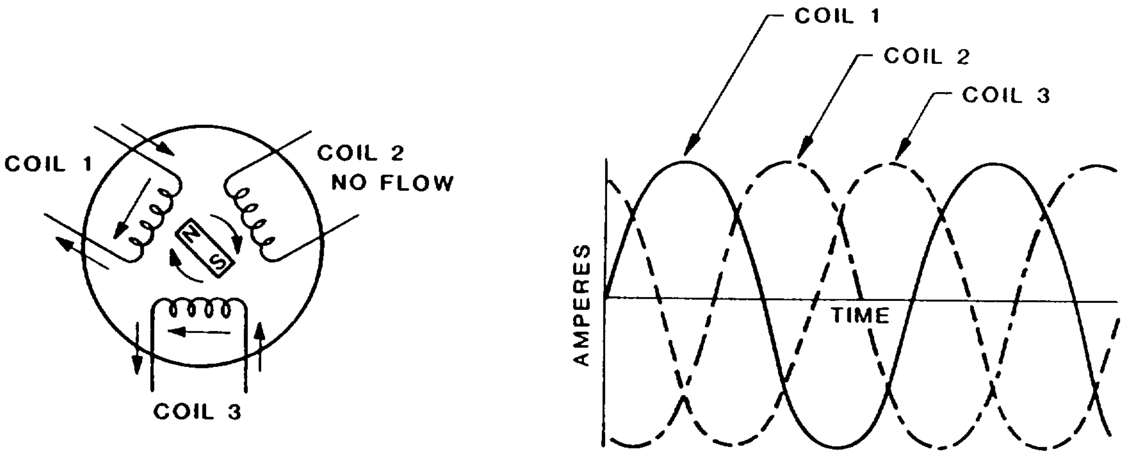


FIGURE A-10. Three-phase power generation.

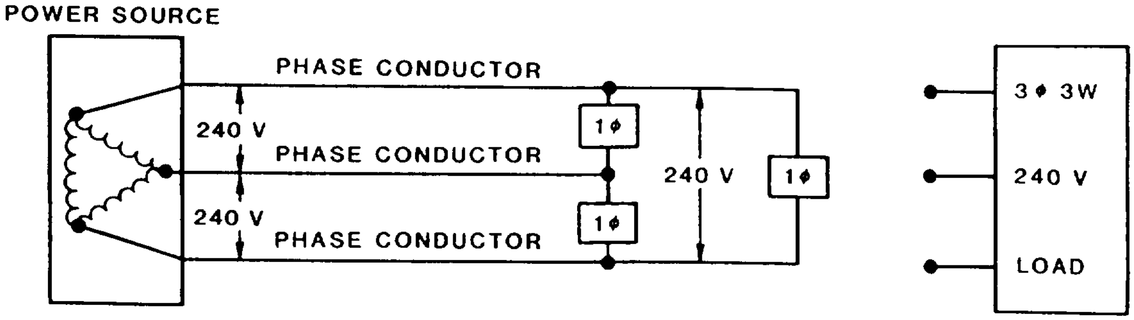


FIGURE A-11. Delta connected three-phase power.

c. Four-wire systems (30-4W). Figure A-12 shows a three-phase, four-wire system using a connection. here are two voltages simultaneously available from this system: phase-to-neutral voltage and phase-to-phase voltage. Note that the phase-to-phase voltage is equal to 1.73 times the phase-to-neutral voltage (208/120V). As in the single-phase system, the loads between the neutral and the phase wires should be balanced to reduce the current in the neutral to a minimum. Any 10-2W, 120-volt load can be fed power by connecting it between any phase conductor and the neutral. Any 10-2W, 208-volt load can be fed between any two-phase conductors. Any 30-3W, 208-volt load can be fed by connecting it to the three-phase conductors or any 30-4W, 120/208-volt load can be fed power by connecting it to any four conductors. The delta-based connection is seldom used on low-voltage power distribution systems. There are several reasons for this, such as higher voltages to ground and poorer suppression of unwanted harmonics. The wye system must also use a fifth conductor which is an equipment protection (green-wire) grounding conductor required by the National Electric Code (NEC) .

40.14 Reasons for using ac power. One of the most important reasons for using ac power generation and distribution is that it can be readily changed by use of a transformer. With a transformer, a particular ac or varying voltage can be raised or lowered to the value required by the load. A basic transformer is relatively uncomplicated, as shown in figure A-13. In this case, a conductor of particular type and size is wound around part of an iron core to form the input or primary side. Another conductor selected and sized to provide the desired output characteristics is wound on another part of the core for a secondary winding.

a. When a voltage (also referred to as electromotive force or emf) is applied to the primary side, magnetic lines of force are created that cut across the secondary winding and result in an induced secondary voltage. For this action to continue, the voltage in the primary side must continue to change in value or reverse in polarity. When the voltage reverses, a voltage of opposite polarity appears in the secondary winding.

b. The ratio of the number of turns in the primary and secondary windings determine whether a transformer is a voltage step-up or step-down device. Since the primary and secondary power theoretically remains the same (except for such things as flux leakage and resistance losses), the secondary current must decrease as voltage increases or increase as voltage decreases. Transformers are required for load isolation and to match the voltages in the distribution system to those required by the load.

50. Power usage data collection.

50.1 DoD worksheets. DoD facility power system load tabulation worksheets may be used to estimate total power requirements and an estimate of backup or power conversion equipment loads. See figures A-14 and A-15.

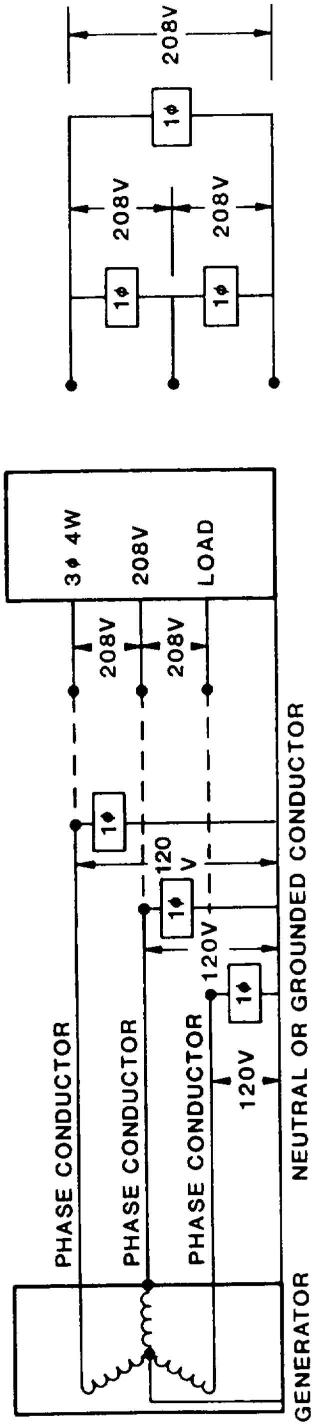


FIGURE A-12. Wye connection three-phase power.

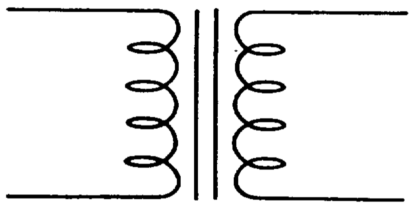


FIGURE A-1 3. Basic transformer configuration.

DoD FACILITY ELECTRICAL POWER SYSTEM LOAD TABULATION WORKSHEET *

FACILITY LOCATION ______
SUPPLY VOLTAGE ______ FREQUENCY ______ PHASE ______
SUPPLY SECONDARY TRANSFORMER CONNECTION DELTA ______ WYE ______

ITEM #	FUNCTIONAL DESCRIPTION OF STATION LOAD **	POWER FREQ REQ'D IF OTHER THAN 60 Hz	POWER HEIRARCHY DESIGNATION				BRANCH FEEDER #	PHASE		PHASES USED	TYPE OF BACKUP OR POWER CONVERSION EQUIPMENT REQUIRED (IN kW)						NOTES
			NO	NT	NCT	CT		1φ	3φ		1 NONE	2 ENGINE-GENERATOR	3 MOTOR-GENERATOR	4 STANDBY UPS	5 ON-LINE UPS	6 REDUNDANT OR PARALLEL UPS	
										TOTALS							TOTAL EST POWER

* SEE 50.2 OF APPENDIX A FOR SUGGESTED PROCEDURE

** IF LOAD IS AN ELECTRICAL MOTOR, OBTAIN DATA BY USING SHEET 2.

LEGEND NO NON-OPERATIONAL NT NON-TECHNICAL NCT NON-CRITICAL TECHNICAL CT CRITICAL TECHNICAL

PAGE ______ OF ______

FIGURE A-14. Example DoD facility electrical power system load tabulation worksheet.

DoD FACILITY LOAD TABULATION WORKSHEET FOR ELECTRIC MOTORS

ITEM + FROM WORK-SHEET 1	NAMEPLATE MOTOR INFORMATION				STARTING LOAD*			CONTINUOUS LOAD (RUNNING/STATIC)					NOTES
	HP	NEMA CODE	ϕ	VOLTS	kVA	PF	kW**	VOLTS	AMPS	kVA	PF	kW	

LOCKED ROTOR LOAD PER MANUFACTURER OR TABLE A-4

**(LRkVA CAN BE DETERMINED BY USING LOCKED ROTOR AMPERES FOR SINGLE PHASE BY $\text{kVA} = \frac{\text{VOLTS X AMPERES}}{1000}$ OR FOR 3-PHASE BY $\text{kVA} = \frac{\text{VOLTS x AMPERES x } \sqrt{3}}{1000}$)

PAGE _____ OF ___

FIGURE A-15. Example facility load tabulation worksheet for electrical motors.

50.2 Sizing procedures. The suggested steps for sizing the facility power load are:

a. Serially number and describe all facility power loads. List in the order most convenient for data collection and use as many sequentially numbered sheets as needed.

b. List power frequency required if other than 60 Hz.

c. Establish power hierarchy designation for the particular load (see 4.2.10 of volume I).

d. Indicate branch feeder number when assigned.

e. Indicate phases required by the load and, when assigned, show phase A, B, C, as appropriate.

f. Enter power consumption of the load in kW in columns 1 through 6, as appropriate. It is important to accurately determine real power consumed. Since inductive loads, such as electric motors, typically represent a low power factor, sheet 2 (DoD facility load tabulation worksheet for electric motors), should be used to determine the kW figure to be entered on sheet 1. The power factor of switch-mode power supplies can also be low. If the manufacturer has not incorporated automatic power factor correction in his design, he must be asked to provide consumption data.

g. Care must be exercised in obtaining total estimated power consumption - this figure will normally be the total of columns 1 and 2. The individual totaling of columns 3 through 6 assists in sizing power conditioning equipment.

The determination of engine-generator set(s) size (column 2) is not a simple problem because load shedding, sequencing, simultaneous starts, etc., are all factors. The data obtained, after considering all the factors, may also be used to determine transfer switch size and rating. Final selection of engine-generator set size must also include a factor for future load increases.

60. Useful power conversions and tables. The information in tables A-I through A-VII is intended for use in the facility planning phase to estimate loads, voltage drops, etc. Following equipment selection, the manufacturer should be consulted for exact specifications. The tables concerning sizing of electrical distribution conductors are for quick reference and should be compared with the current version of the National Electric Code (NEC) before a final selection is made.

TABLE A-I. Electrical formulas for determining watts, kilowatts, amperes, kilovolt-amperes, and horsepower.

$$\text{Torque in lb-ft} = \frac{\text{hp} \times 5{,}250}{\text{rpm}} \qquad \text{hp} = \frac{\text{Torque} \times \text{rpm}}{5{,}250}$$

$$\text{rpm} = \frac{120 \times \text{frequency}}{\text{no. of poles}}$$

Where:

hp = horsepower
rpm = resolutions
P = number of poles

ELECTRICAL FORMULAS

To find	Alternating current three-phase
kVA	$\frac{1.73 \times I \times E}{1{,}000}$
Amperes when horsepower is known	$\frac{\text{hp} \times 746}{1.73 \times E \times \text{Eff} \times \text{PF}}$
Amperes when kilowatts are known	$\frac{\text{kW} \times 1{,}000}{1.73 \times E \times \text{PF}}$
Amperes when kVA is known	$\frac{\text{kVA} \times 1{,}000}{1.73 \times E}$
Kilowatts	$\frac{1.73 \times I \times E \times \text{PF}}{100}$
Horsepower (output)	$\frac{1.73 \times I \times E \times \text{Eff} \times \text{PF}}{746}$

I = Amperes
E = volts
Eff = Efficiency
hp = horsepower

kVA = Kilovolt-Amperes
kW = Kilowatts
PF = Power factor

TEMPERATURE CONVERSION

Degree C = (Degree F - 32) x 5/9
Degree F = (Degree C x 9/5) + 32

TABLE A-I. Electrical formulas for determining watts, kilowatts, amperes, kilovolt-amperes, and horsepower - continued.

Rules of thumb

At 3600 rpm, a motor develops 1.5 lb-ft per hp.
At 1800 rpm, a motor develops 3 lb-ft per hp.
At 1200 rpm, a motor develops 4.5 lb-ft per hp.
At 550 and 575 volts, a 3-phase motor draws 1 amp per hp.
At 440 and 460 volts, a 3-phase motor draws 1.25 amp per hp.
At 220 and 230 volts, a 3-phase motor draws 2.5 amps per hp.

$$\text{Voltage tolerance } \% = \frac{\text{No load-full load voltage}}{\text{x rated voltage}} \text{ X } 100$$

$$\text{Voltage regulation } \% = \frac{\text{No load-full load voltage}}{\text{full load volts}} \text{ X } 100$$

$$\text{Speed regulation } \% = \frac{\text{No load-full load}}{\text{full load speed (rpm)}} \text{ X } 100$$

OHM's LAW: Ohm's law states that the current in an electric circuit is equal to the pressure (voltage) divided by the resistance. This can be expressed by the equation:

$$\text{amperes} = \frac{\text{volts}}{\text{ohms}}$$

The equations may be written:

DC OHM’S LAW: $E = I \times R$ $\qquad I = \frac{E}{R} \qquad R = \frac{E}{1}$

AC OHM’S LAW: $E = IZ$ $\qquad I = \frac{E}{Z} \qquad Z = \frac{E}{I}$

Where:

E = volts
F = frequency

I = amperes
R = resistance (ohms)
Z = impedance (ohms)

TABLL A-II. Approximate ampere ratings of ac generators.

POWER FACTOR			SINGLE PHASE		THREE PHASE		
80%		Unity	120-V	120-/240-V	120-/208-V	120-/240-V	240-/480-V 277-/480-V
kW	kVA	kW=kVA	amp	amp	amp	amp	amp
10.0	12.5	12.5	104	52	35	30	15
12.5	15.6	15.6	130	65	43	38	19
		15.0	125	63	42	36	18
15.0	18.75	18.75	156	78	53	45	23
		17.5	146	73	49	42	21
17.5	21.87	21.87	182	91	61	53	26
		20.0	167	84	56	48	24
20.0	25.0	25.0	208	104	70	60	30
25.0	31.25		260	130	87	75	38
				125	83	72	36
30.0	37.5			156	104	90	45
35.5	43.75			182	122	105	53
40.0	50.0			208	139	120	60
45.0	56.25			234	156	135	68
50.0	62.5			260	174	151	75
55,5	68.75			286	191	166	83
60.0	75.0			313	209	181	90
65.0	81.25			339	226	196	98
70.0	87.5			365	244	210	105
75.5	93.75			390	261	226	113
80.0	100.0			417	278	240	120
85.0	106.25			443	295	256	128
90.0	112.5			468	312	271	135
100.0	125.0			520	348	300	150
110.0	137.50			573	382	332	166
115.9	143.75			595	400	346	173
125.0	156.25			651	435	376	188
140.0	175.0			729	486	421	211
150.0	187.5				521	452	226
155.0	193.75				538	468	234
165.0	206.25				575	498	248
170.0	212.5				591	513	256
175.0	218.75				609	527	263
190.0	237.5				660	573	286
200.0	250.0				696	602	300
230	287.5				799	693	346
250	312.5				867	751	376
300	375				1042	903	452
350	437.5				1215	1054	527
400	500				1390	1204	602
450	562.5				1560	1354	676
500	625.0				1734	1500	751

NOTE: Always use kVA ratings when shown or known.

TABLE A-III. Typical running current requirements of motors.

HP	120 V l-Phase ac		240 V l-Phase ac		240 V 3-Phase ac		115 Vdc		230 Vdc	
	C	W	C	W	C	W	C	W	C	W
1/6	4.4	14	2.2	14						
1/4	5.8	14	2.9	14			2.9	14		
1/3	7.2	14	3.6	14			3.6	14		
1/2	9.8	14	4.9	14	2.0	14	5.2	14	2.6	14
3/4	13.8	12	6.9	14	2.8	14	7.4	14	3.7	14
1	16.0	12	8.0	14	3.b	14	9.4	14	4.7	14
1 -1/2	20.0	10	10.0	14	5.2	14	13.2	12	6.6	14
2	24	10	12.0	14	5.8	14	17.0	10	8.5	14
3	34	6	17.0	10	9.6	14	25.0	8	12.2	12
5	56	4	28.0	8	15.2	12	40.0	6	20.0	10
7-1/2	80	1	40.0	6	22.0	10	58.0	3	29.0	8
10	100	o	50.0	4	28.0	8	76.0	2	38.0	6

C = Full rated current in amperes (amperes while starting are much higher).
W = Minimum wire size permitted by code; larger sizes often required - check distance for voltage drop.

TABLE A-IV. Locked-rotor current conversion table for motor circults and controllers.

	Typical motor locked-rotor current (in amperes)					
MAX. HP RATING	SINGLE-PHASE		TWO- OR THREE-PHASE			
	120 V	240 V	120 V	208 V	240 V	480 V
1/2	58.8	29.4	24	14	12	6
3/4	82.8	41.4	33.6	19	16.8	8.4
1	96	48	42	24	21	10.8
1-1/2	120	60	60	34	30	15
2	144	72	78	45	39	19.8
3	204	102		62	54	27
5	336	168		103	90	45
7-1/2	48.0	240		152	132	66
10	600	300		186	162	84
15				276	240	120
20				359	312	156
25				442	384	192
30				538	468	234
40				718	624	312
50				862	750	378

TABLE A-V. Recomnended wire size (AWG) for a three-phase motor.

	HORSEPOWER									
VOLTS	1-3	5	7-1/2	10	15	20	25	30	40	50
208	14	10	8	6	4	3	1	0	000	000
240	14	12	10	8	6	4	3	1	0	000
480	14	14	14	12	10	8	6	6	4	3

TABLE A-VI. Characteristics of conductors.

CARRYING CAPACITIES (30 °C 86 °F)						
				In raceway or cable	In free air	
Wire size	Area (Circular mills)	Ohms per 1000 ft. (25 °C or 77 °F)	Bare Copper (Pounds per 1000 ft.)	Rubber covered (Type R)	Rubber covered (Type R)	Weather proof (Type WP)
14	4,109	2.575	12.43	15	20	30
12	6,520	1.619	19.77	20	25	40
10	10,380	1.018	31.43	30	40	55
8	16,510	.641	49.98	40	55	70
6	26,240	.410	79.46	55	80	100
4	41,740	.259	126.4	70	105	130
2	66,360	.162	205.0	95	140	175
1	83,690	.129	258.9	110	165	205
0	105,560	.102	326.0	125	195	235
00	133,080	.0811	411.0	145	225	275
000	167, 770	.0642	518.0	165	260	320
0000	211,600	.0509	640.5	195	300	370

TABLE A-VII. Wire sizes for 120-volt-dc or -ac unity power factor, 2-percent voltage drop (2.4 volts).

		WIRE SIZE (AWG)						
		14	12	10	8	6	4	2
WTTS (Note Z)	AMPERES AT 120 VOLTS (Note 3)	ALLOWABLE DISTANCE (feet) (Note 1)						
100	.84	550	880	1330	2080	3400	5500	8500
200	1.67	275	440	665	1060	1690	2750	4300
300	2.50	183	290	450	710	1130	1850	2840
400	3.33	137	220	330	530	840	1380	2150
500	4.16	110	175	265	430	680	1100	1700
750	6.25	73	115	177	285	450	740	1140
1000	8.33	55	83	130	214	340	550	850
1500	12.50	36	57	88	146	225	365	575
2000	16.66	27	42	68	104	166	275	430
2500	20.80	22	37	52	83	135	220	365
3000	25.00	18	26	42	68	115	188	285
3500	29.20		23	37	63	94	155	245
4000	33.30		21	31	52	83	134	217
4500	37.50		15	29	46	73	119	176
5000	41.80			26	42	67	108	166
6000	50.00			21	36	57	88	140
7000	58.30				29	46	78	119
8000	66.60				26	42	67	104
9000	75.00					36	57	93
10000	83.30					31	52	83

NOTES:

1. Figures represent a one-way distance in feet for a two-wire run. If a 4-percent voltage drop is permissible, double the distances listed.

2. For other voltages (120, 240, etc.), use the amperes column - disregard the watts column. If only a l-percent voltage drop is allowable, divide the distances listed by 2.

3. For 240-V and 480-V circuits, the information in the table can be used if distances are changed as follows:

TABLE A-VII. Wire sizes for 120-volt-dc or -ac unity power factor, 2-percent voltage drop (2.4 volts) - continued.

a. For single-phase ac circuits:

Using watts - 4 x distance for 240 volts
16 x distance for 480 volts

Using amps - 2 x distance for 240 volts
4 x distance for 480 volts

b. For three-phase ac circuits (assuming a balanced three-phase load):

Using amperes - 4 x distance for 240 volts
8 x distance for 480 volts

Formula for determining wire size under any other condition:

a. Direct current and single-phase systems:

$$CM = \frac{D \times I \times 22}{Ed}$$

b. Three-phase, three-wire systems:

$$CM = \frac{D \times I \times 19}{Ed}$$

Where:

CM = Circular mills - wire size (see table VI)

I = Current in amperes (in the case of three-phase, it is the current in each wire)

D = Single distance (one-way length) of the circuit in feet

Ed = Allowable voltage drop in volts (2 percent of 115 volts is 2.3 volts, etc.)

TABLE A-VIII. Units, constants, frequency spectrum, and conversion factors.

A. Conversion factors.

TO CONVERT	TO	MULTIPLY BY	CONVERSELY, MULTIPLY BY
Ampere-hours	Coulombs	3,600	2.770 x 10-^{4}
Atmospheres	millimeters of mercury, 0° C	760	1.32 x 10^{-3}
Atmospheres	inches of mercury, 0° C	29.92	3.34 x 10^{-2}
Atmospere	pounds of mercury, 0° C	14.7	6.8 x 10^{-2}
Atmosphere	kilopascals	101.3	9.87 x 10^{-3}
Btu (British thermal unit)	Foot-pounds	778.3	1.285 x 10^{-3}
Btu	Joules	1,054.8	9.48 x 10^{-4}
Btu	Kilogram-calories	.252	3.969
Btu	Horsepower-hours	3.929 x 10-^{4}	2,545
Centigrade	Fahrenheit	(C^{0} X 9/5) + 32	(F^{0}- 32) x 5/9.
Centigrade	Kelvin	add 273	subtract 273
Circular roils	Square centimeters	5.067 x 10-^{6}	1.973 x 105
Circular roils	Square mils	.7854	1.273
Cubic inches	Cubic centimeters	16.39	6.102 x 10^{-2}
Cubic inches	Cubic feet	5.785 x 10-^{4}	1,728
Cubic inches	Cubic meters	1.639 x 10-5	6.102 x 10^{4}
Cubic meters	Cubic feet	35.31	2.832 x 10^{-2}
Cubic meters	Cubic yards	1.308	.7646
Degrees (angular measure)	Radians	.01745	57.2958
Dynes	Pounds	2.248 x 10-^{6}	4.448 x 10^{5}
Ergs	Foot-pounds	7.367 x 10-^{8}	1.356 x 10^{7}
Foot-pounds	Horsepower-hours	5.05 x 10^{-7}	1.98 x 10^{6}
Foot-pounds	Kilogram-meters	.1383	7.233
Foot-pounds	Kilowatt-hours	3.766 x 10^{-7}	2.655 x 10^{6}
Grams	Dynes	980.7	1.02 x 10^{-3}
Grams	Ounces (avoirdupois)	3.527 x 10^{-2}	28.35
Grams per cm	Pounds per inch	5.6 x 10^{-3}	178.6
Grams per cubic cm	Pounds per cu. inch	3.613 x 10^{-2}	27.68

TABLE A-VIII. Units, constants, frequency spectrum, and conversion factors - Continued.

TO CONVERT	TO	MULTIPLY BY	CONVERSELY, MULTIPLY BY
Grams per sq. cm	Pounds per sq. foot	2.0481	.4883
Horsepower (550 ft.-lb. per sec.)	Foot-lb. per minute	3.3×10^{4}	3.03×10^{-5}
Horsepower (550 ft.-lb. per sec.)	Btu per minute	42.41	2.357×10^{-2}
Horsepower (550 ft.-lb. per sec.)	Kg-calories per minute	10.69	9.355×10^{-2}
Horsepower (550 ft.-lb. per sec.)	Kilowatts	0.7457	1.341
Horsepower (Metric) (542.5 ft.-lb. per sec.)	Horsepower (550 ft.-lb. per sec)	.9863	1.014
Joules	Foot-pounds	.7376	1.356
Joules	Ergs	10^{7}	10^{-7}
Kilogram-calories	Kilojoules	4.186	.2389
Kilograms	Pounds (avoirdupois)	2.205	.4536
Kg per sq. meter	Pounds per sq. foot	.2048	4.882
Kilowatt-hours	Btu	3,413	2.93×10^{-4}
Kilowatt-hours	Foot-pounds	2.655×10^{6}	3.766×10^{-7}
Kilowatt-hours	Joules	3.6×10^{6}	2.778×10^{-7}
Kilowatt-hours	Kilogram-calories	860	1.163×10^{-3}
Kilowatt-hours	Kilogram-meters	3.671×10^{5}	2.724×10^{-6}
Liters	Cubic meters	.001	1,000
Liters	Chic Inches	61.02	1.639×10^{-2}
Liters	Gallons (liq. US)	.2642	3.785
Liters	Pints (liq. US)	2.113	.4732
Poundals	Dynes	1.383×10^{4}	7.233×10^{-5}
Poundals	Pounds (avoirdupois)	3.108×10^{-2}	32.17
Radians	Degrees	57.2958	.01745
Sq inches	Circular mils	1.273×10^{6}	7.854×10^{-7}
Sq inches	Sq centimeters	6.452	.155
Sq feet	Sq meters	9.29×10^{-2}	10.76
Sq miles	Sq yards	3.098×10^{6}	3.228×10^{-7}
Sq miles	Sq kilometers	2.59	.3861

TABLE A-VIII. Units, constants, frequency spectrum, and conversion factors - Continued.

TO CONVERT	TO	MULTIPLY BY	CONVERSELY, MULTIPLY BY
Sq millimeters	Circular mils	1,973	5.067×10^{-4}
Tons, short (avoir 2,000 lb.)	Tonnes (1,000 Kg.)	.9072	1.102
Tons, long (avoir 2,240 lb.)	Tonnes (1,000 Kg.)	1.016	.9842
Tons, long (avoir 2,240 lb.)	Tons, short (avoir 2,000 lb)	1.120	.8929
Watts	Btu per min	5.689×10^{-2}	17.58
Watts	Ergs per sec	10^{7}	10^{-7}
Watts	Ft-lb per minke	44.26	2.26×10^{-2}
Watts	Horsepower (550 ft-lb per sec.)	1.341×10^{-3}	745.7
Watts	Horsepower (metric) (542.5 ft-lb per sec.)	1.36×10^{-3}	735.5
Watts	Kg-calories per min	1.433×10^{-2}	69.77

B. Luminance conversion factors.

---

1 nit = 1 candela/square meter
1 stilb = 1 candela/square centimeter
1 apostilb (international) = 0.1 millilambert = 1 blondel
1 apostilb (German Hefner) = 0.09 millilambert
1 lambert = 1,000 millilamberts

Multiply number of ↘ To obtain number of	footlambert	candela per sq meter	millilambert	candela/sq in	candela per sq ft	stilb
footlambert	1	0.2919	0.929	452	3.142	2,919
candela/sq m	3.426	1	3.183	1,550	10.76	10,000
millilambert	1.076	0.3142	1	487	3.382	3,142
candela/sq in	0.00221	0.000645	0.00205	1	0.00694	6.45
candela/sq ft	0.3183	0.0929	0.2957	144	1	929
stilb	0.00034	0.0001	0.00032	0.155	0.00108	1

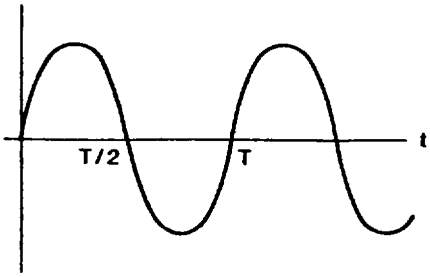


FIGURE A-6. Sine wave generation.

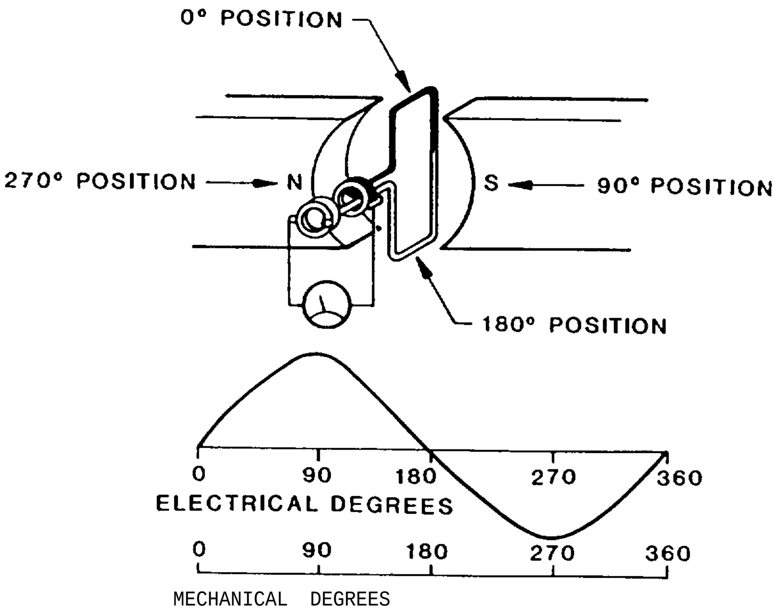


FIGURE A-7. Generator construction.

FIRE PROTECTION

10. Scope. Damage from fires (and the consequent disruption of operations) can be minimized by the installation of appropriate fire protection systems. The system, or systems (more than one might be necessary), must protect the entire facility and must be of a type appropriate to the facility. The wrong type of system can, like the fire itself, be a threat to the facility. For example, an automatic water sprinkling system can damage electronic equipment, and would be inappropriate for a communications or data processing facility. Often, it is necessary to employ several different types of systems at a given facility. Systems commonly used at DoD facilities include the following:

20. Applicable documents. MIL-HDBK-1008, Fire Protection For Facilities Engineering, Design, and Construction.

30. Halon 1301 system. Halon is a colorless, odorless, nonconductive gas (bromotriflouromethane), which when released in a confined area. extinguishes fires by inhibiting the-chemical reaction between fuel and oxygen. It is used in place of $C0_2$ systems because of the extreme personnel safety hazard created by use of $C0_2$ in confined spaces. There are two types of Halon 1301 systems used at fixed installations: (1) total flooding, and (2) local application. The total flooding system is designed to cover a large area, and would normally be the system used in a computer facility. The local application system focuses on a single point which may be a critical fire hazard such as flammable liquids or other highly combustible materials. Both systems consist of: (1) a pressurized tank with a control valve that may be electrically or manually activated, (2) automatic detection devices, (3) dispersion heads, and (4) an electronic monitor and control panel. Figure B-1 shows a typical Halon 1301 System.

30.1 Design of facilities using Halon systems. Design of the facility is important if a Halon 1301 system is to be used for fire protection. It is essential that the protected area be constructed with minimal openings so the halon, if released, cannot escape from that area. Windows should be of a type that cannot be opened. All doors should have weatherstripping on the top and sides, with an adjustable door sweep at the bottom. Doors should also have automatic closers and signs on both sides stating that the door must remain closed at all times. All air-handling systems, to include heating, cooling, and ventilating systems, should be connected to the electronic control panel in such a way that all systems will shut down at the first indication of a fire alarm. This prevents air from being forced into the room and diluting the Halon, and also prevents the Halon from being removed from the protected area by return ducts or exhaust fans. Release of Halon may cause an electrostatic charge on ungrounded conductors; therefore, equipment must be grounded in accordance with MIL-HDBK-419. Floor coverings should also be of antistatic material . If an electrostatic charge is allowed to develop, it may reach a potential that could cause a discharge between two objects, which may cause an explosion. Positioning of detectors is also critical. Smoke detectors should be placed away from air conditioning vents which would tend to blow the smoke away from the detector. It is also

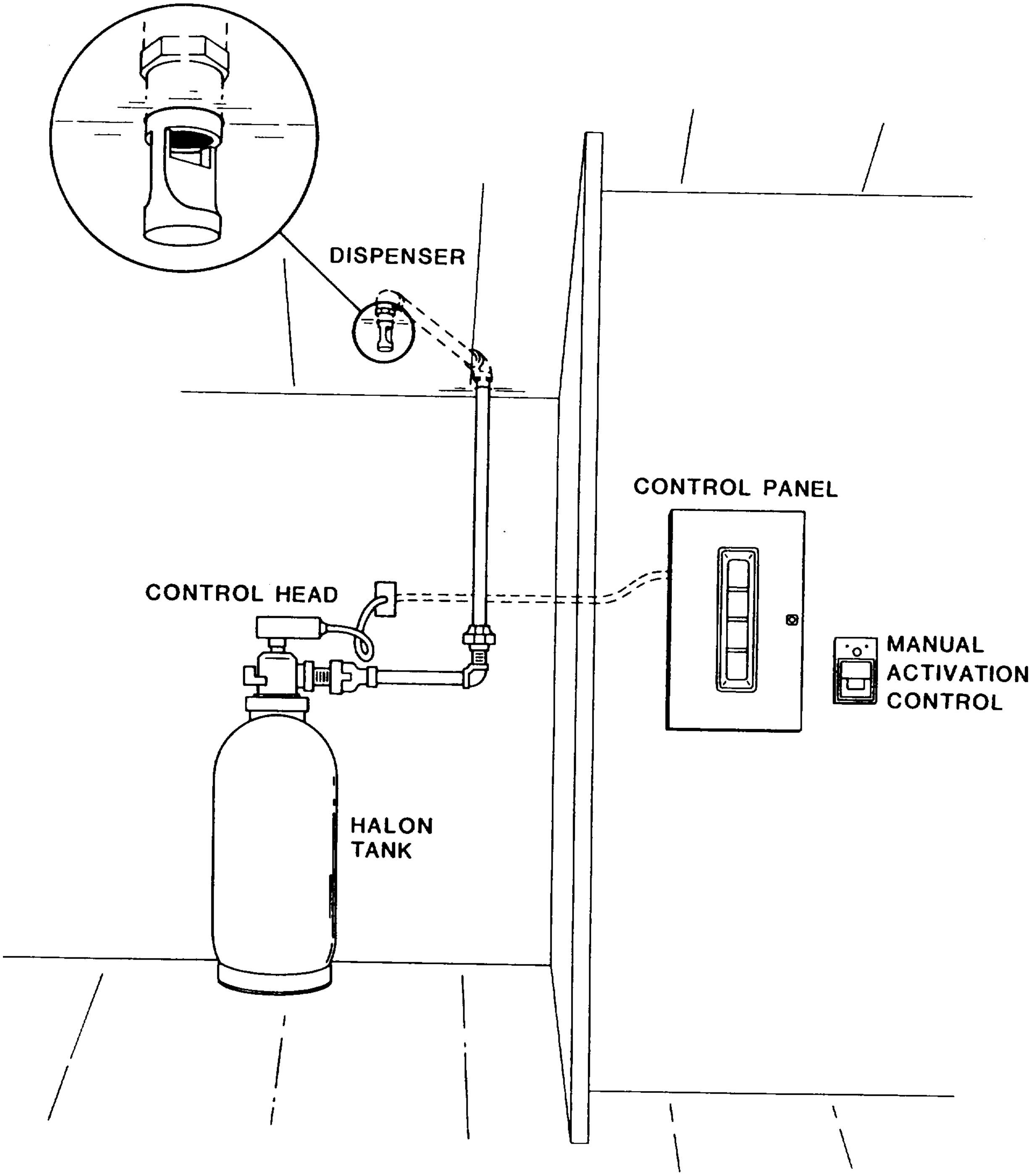


FIGURE B-1. Typical Halon 1301 System.

recommended that a smoke detector be placed near each return air duct and exhaust vent since smoke will natumtlly be drawn out of the room through these vents. This reduces detection time. Smoke and heat detectors should also be installed above ceilings and under raised floors. Detectors under raised floors should be positioned as shown in figure B-2.

30.2 Exposure of personnel to Halon. Exposure to Halon should be avoided whenever possible. There is not serious risk to personnel from exposure to Halon 1301 vapors for brief periods, but exposure for extended periods or to high concentrations may cause dizziness, impaired coordination, and irregular cardiac rhythm. Usually these symptoms disappear when the individual leaves the area, but continued exposure may be fatal. It has also been reported that Halon may cause damage to the earth's ozone layer.

40. Automatic water sprinkling systems. NFPA 13 requires automatic water sprinkling systems to be installed in areas where highly combustible materials are used or stored, or have been used in construction of a building. Other areas should be evaluated to determine if it is practical to install such systems. When designing automatic water sprinkling systems, the following factors must be considered:

a. What is the possibility of fire in the area?

b. What combustible material is used or stored in the area, or was used in construction of the building?

c. Is the area protected by other systems such as a Halon 1301 or an early warning system?

d. Is the equipment density in the area high or low?

e. Will unacceptable damage be caused if the water system is activated, either by a fire or accidentally?

If the likelihood of fire is low and equipment or material is susceptible to water damage, sprinkler systems should be avoided, and a Halon 1301 or an early warning system installed. It may be advisable to avoid sprinkler systems in areas where water pressure is low.

40.1 Types. There are four types of automatic water sprinkling systems: (1) wet-pipe, (2) dry-pipe, (3) pre-action, and (4) deluge. Wet-pipe systems employ automatic sprinklers attached to pipes connected to a water supply. The pipes are filled and the sprinklers discharge water immediately when opened by heat of a fire. The dry-pipe system contains pressurized air or nitrogen. When the sprinklers are opened, as by heat of a fire, the gas pressure drops water pressure from the supply to open a valve, and water flows into the pipes to be dispensed from the sprinklers. The pre-action system employs automatic sprinklers connected to pipes containing air that may or may not be under pressure. A supplemental fire detection system is installed in the same area as the sprinkling system. When the detection system is activated, a valve opens, permitting water to flow into the pipes and to be discharged through the sprinklers (which have been opened by the fire). The deluge system is similar to the pre-action system, but uses open sprinklers instead of closed ones.

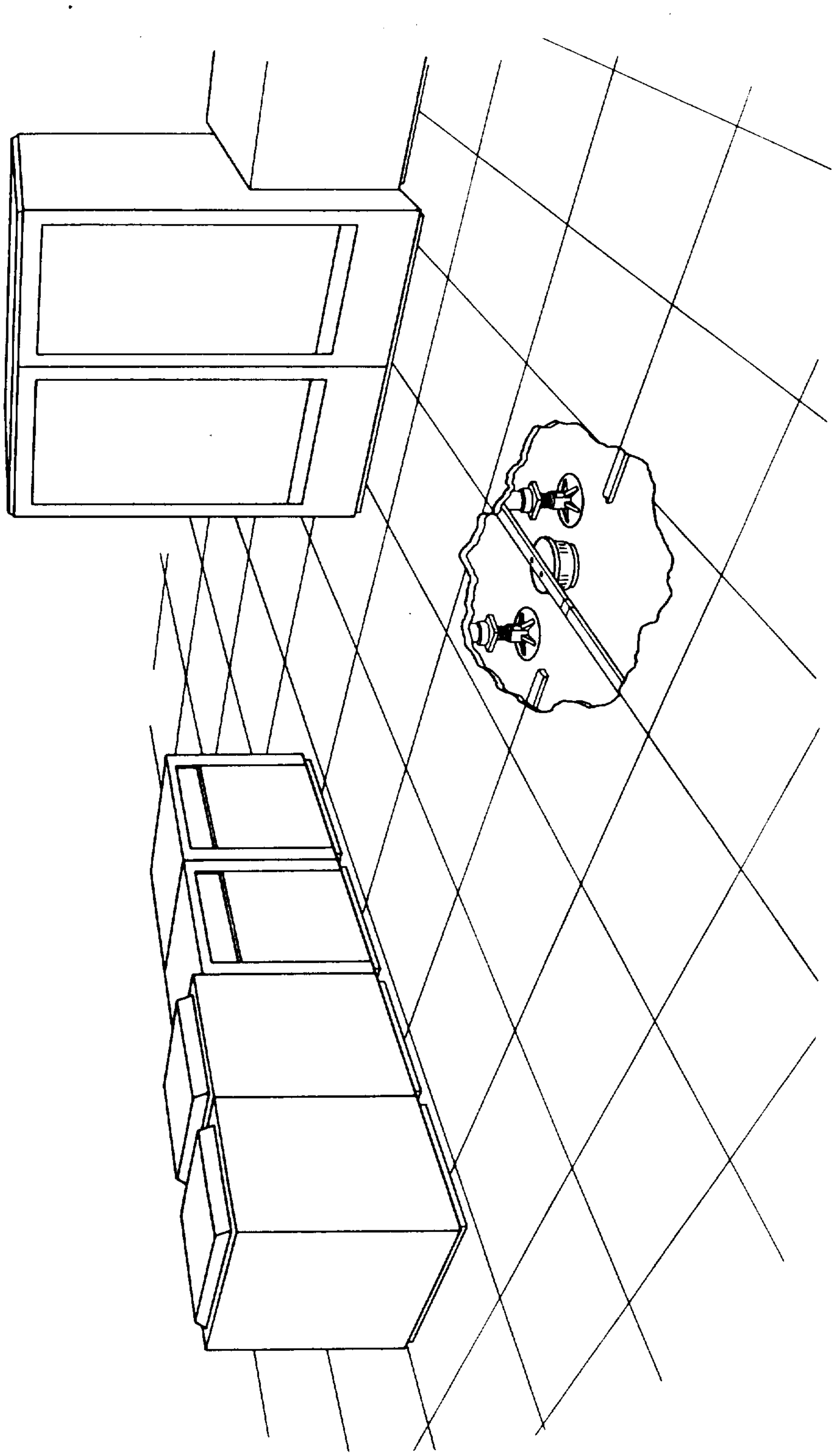


FIGURE B-2. Under-floor detector mounting.

40.2 Installation, When installing an automatic water sprinkling system? it is important to place the sprinklers so they will provide total, overlapping coverage of the protected area. If high objects block coverage of certain spaces within the protected area, additional sprinklers should be installed to provide total coverage. Because they are controlled and activated electronically, pre-action and deluge systems are preferable to other types of sprinkler systems. An electronic control panel should be installed in the protected area. This panel should be connected to the central control panel or monitor station, and should be equipped with an abort function so that water dumping could be prevented if the system should be accidentally activated. If a wet-pipe or dry-pipe system is used, there is little chance of stopping water dumping in the event of accidental activation.

50. Early Warning System. The early warning system is designed to provide fire protection in areas where use of an automatic water sprinkling system may damage a facility, and use of a Halon 1301 system is not warranted due to low equipment density. An early warning system consists of heat and smoke detectors, local audible and visual alarms, an electronic monitor and control panel, and a reliable means of communication. The heat and smoke detectors are designed to detect the earliest signs of smoke or unusual temperature rise. When the system is activated, the local alarms are energized, and a signal is automatically transmitted to a monitor station.

For this type of system to be effective: (1) the communication link between the facility and the monitor station must be highly reliable. The desired reliability is 95 percent. Since this may not be attainable in some areas, the reliability should not be below 80 percent, and (2) the response time of the fire department after notification should be 5 minutes or less. If the response is more than 5 minutes, other protective systems should be considered.

The communication link may be a dedicated line through the local telephone exchange, an automatically dialed high-priority telephone circuit, or a radio link. When using either type circuit through the telephone exchange, 24 Vdc must be provided. This may be supplied by the facility central control panel or by the telephone exchange. When the system is activated, the polarity of the dc is reversed, triggering an alarm at the monitor station. The monitor station then notifies the support fire department.

When designing an early warning system, the first step is to determine the reliability of the communication link. Telephone exchange records for the last six months should be reviewed to determine the number and cause of outages, average downtime, and corrective action taken. If the period of time reviewed does not cover the period of peak thunderstorm activity in the area, the latter period should also be reviewed. If acceptable reliability cannot be achieved, an early warning should not be used. If a radio is to be used, it is important to determine if any equipment in the facility can interfere with and reduce the reliability of the radio link. It is also important to survey adjacent facilities and the line-of-sight path between the facility and the monitor station to identify other sources of potential interference (e.g., radio or television broadcast stations). Since the early warning system is usually used without a fixed fire extinguishing system, it is recommended that portable fire extinguishers be strategically placed throughout the facility.

60. Detectors. The selection, positioning, and installation of detectors depends on facility design, equipment configuration, type of equipment, materials in the construction of the building used, and the anticipated fire potential. Usually a combination of heat, smoke, and flame detectors works better than one type of detector used alone. Typical detectors are shown in figures B-3a through B-3d.

60.1 Heat detectors. Heat detectors have the lowest false alarm rate, but are also the slowest in detecting fires. They are designed to activate a fire alarm when the temperature of their elements exceeds a fixed temperature rating (usually 135 °F (57 °C) or 200 °F (93 °C)). There are three common types of heat detectors: (1) eutectic (fusible) metal , (2) glass bulb, and (3) bimetal. The eutectic type uses alloys of bismuth, cadmium, lead, or tin for elements. These elements are designed to melt at the rated temperature, thus activating the alarm. This type is not restorable, and therefore must be replaced after it has been activated. The glass bulb detector is the least commonly used type. It consists of a switch which is normally open, a built filled with liquid under high pressure with a small bubble. When heated, the liquid expands and compresses the air bubble. When the air bubble has been totally absorbed, a rapid increase in pressure occurs and the bulb breaks, closing the switch and activating the alarm. There are two types of bimetal detectors: (1) the bimetal strip, and (2) the bimetal disc. Both types employ a switch consisting of two metals with different thermal expansion coefficients. When the metals are heated, the metal strip or disc with the higher expansion coefficient bends toward the one having the lower expansion coefficient. When the two pieces of metal contact each other, the alarm is activated. When the source of heat has been eliminated, the metals cool and separate, thus restoring the detector to normal monitoring condition. The strip detector, although effective, has a relatively slow response time. The disc type has a rapid response time and is more effective for early fire detection. A major disadvantage of bimetal detectors is that they often cause false alarms due to vibration. This is especially true as the room temperature approaches the threshold temperature of the detector.

60.2 Smoke detectors. There are two common types of smoke detectors: photoelectric detectors, and (2) ionization detectors. Photoelectric detectors operate by sensing a change in the intensity of light received by a photo receptor. When smoke is present, light is reflected onto the light-sensitive photocell, causing its resistance to decrease. This causes an increase in current which is electronically amplified to produce an alarm voltage. The advantages of photoelectric detectors are: (1) fast response to smoldering fires, (2) fast response to smoke regardless of the distance smoke has travelled, (3) fast response to overheated pvc wire insulation, (4) insensitivity to air velocity, and (5) the ability to install in areas where controlled fires are present or where nonflammable gases or vapors are normally found. Some disadvantages are slow response to: (1) fast-flaming fires, and (2) combustion particles having a diameter smaller than the wavelength of the light source.

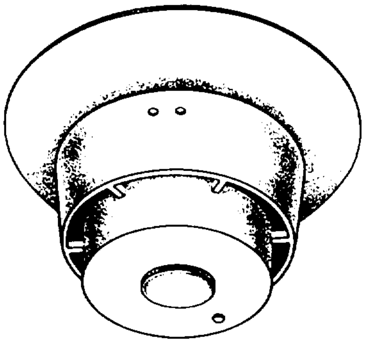


FIGURE B-1A PHOTOELECTRIC SMOKE DETECTOR

FIGURE B-3a. Photoelectric smoke detector.

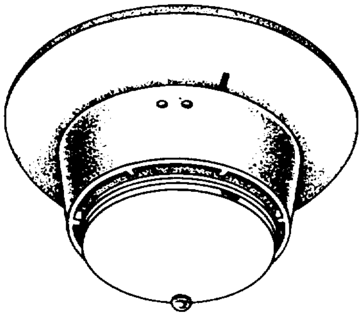


FIGURE B-1B IONIZATION SMOKE DETECTOR

FIGURE B-3b. Ionization smoke detector.

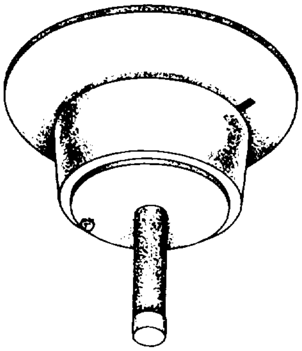


FIGURE B-1C HEAT DETECTOR

FIGURE B-3c. Heat detector

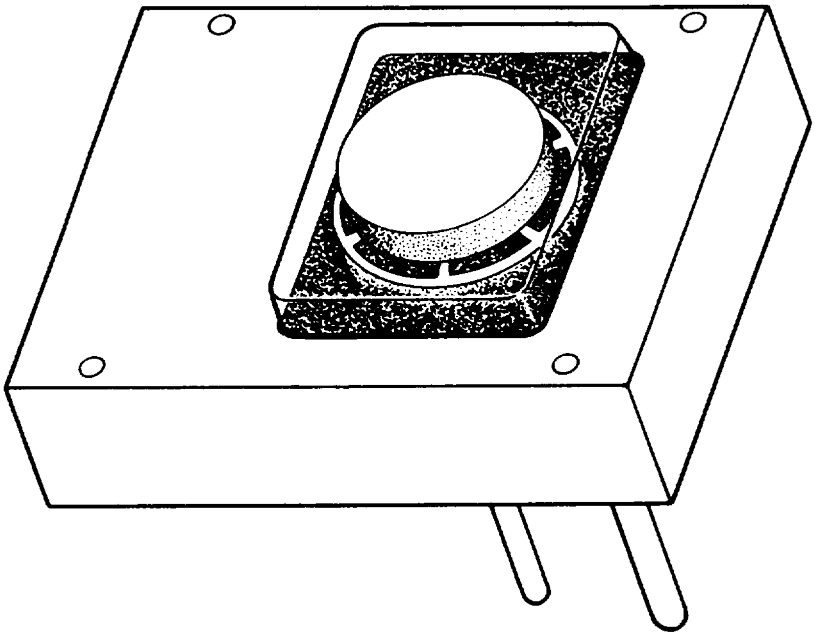


FIGURE B-3a. Duct detector.

60.3 Ionization detectors. Ionization detectors operate by sensing a change in the electrical properties of a chamber containing minute quantities of radioactive material. Alpha emissions from this material ionize the air between two plates. When combustion products from a fire enter the chamber, they change the impedance of the chamber, causing a voltage shift and triggering an alarm. The advantages of ionization detectors are: (1) quick response to fast-flaming fires, (2) quick response to fires that produce only a small amount of smoke and no visible flame, and (3) sensitivity to a wide range of combustion products. The disadvantages are: (1) slow response time to smoldering fires, (2) changes in sensitivity due to altitude or the presence of radiation sources in the environment, and (3) changes in sensitivity due to sudden changes in temperature, humidity, and barometric pressure. Many ionization detectors, however, employ designs to compensate for the effects of temperature, humidity, air pressure, altitude, etc.

60.4 Flame detectors. Flame detectors sense ultraviolet or infrared radiation produced by flames or glowing embers. Flame detectors have the fastest response time of all types of detectors, but, unfortunately also have a high false-alarm rate. Areas in which this type of detector is employed should be designated as nonsmoking. Care must be taken to ensure that no objects are positioned so that they can block the “vision” of the device. This type detector should be used only in areas of extremely high risk, such as fuel storage areas, and should not be used in operations or equipment areas.

60.5 Duct detectors. Duct detectors are typically smoke detectors which are installed inslde air conditioning ducts. They should be placed close to possible sources of fire, such as fan motors or compressors.

70. Fire prevention. The most effective method of fire protection is prevention. All construction materials should be flame retardant. In addition, wall, floor, or roof penetrations should be equipped with a fire-stop barrier to prevent flame or smoke from passing from one area to another. Foamed silicone elastomer is used to provide such a barrier, since it is fire resistant, stable at high temperatures, and easily installed. The foam is sprayed around the penetrations to provide a complete, air-tight seal. Since it is a two-part mixture, the silicone expands when the two parts are mixed, closing around the penetration. Additional treatment may be provided by spraying the foam inside floors, walls, and ceilings.

PHYSICAL SECURITY

10. Scope. The need for providing physical security depends on the geographical location and vulnerability of the facility and the criticality of the mission. Physical security measures may include access control, perimeter fences, perimeter lighting, closed circuit television (CCTV), and an intrusion detection system. This appendix provides general physical security guidelines.

20. Applicable documents. MIL-HDBK-1013/1 , Design Guidelines For Physical Security of Fixed Land-Based Facilities.

30. Access control. There are numerous methods of providing access control. Among these methods are guard force, mechanical or electronic cipher locks, dial combination locks, key locks, and internally controlled electrical door releases. Recent developments in biometric access control can be used for access when permitted by individual service publications. Biometric access control is the method of identification and verification in which the person seeking access is identified by fingerprints, palm pattern and geometry, retinal pattern, voice analysis, signature dynamics, and other methods.

30.1 Guard force. A guard force may be employed to provide access control. This method is quite effective, requiring some form of personal recognition or identification. Usually, access rosters are provided to guard personnel, listing all personnel who are authorized access to the facility. The guard is responsible to positively identify individuals and verify authorization. Since comparing identification by checking the access roster would be too time consuming in large facilities, a pass or badge system may be effective. Passes or badges should include a photograph of the individual to whom they are issued. They must be closely controlled and should be withdrawn when access is no longer authorized. Visitors to the facility should be issued a temporary badge or pass after formal identification has been provided, and the need for access established. Infrequent visitors should be accompanied by an escort (usually a person assigned to the facility) while in the facility. An access roster may be provided to guard personnel for frequent visitors to the facility. These personnel may be granted access as authorized by the local security manager.

30.2 Mechanical or electronic cipher locks. Cipher locks are combination locks which are opened by pushing a series of buttons or switches. A cipher lock may be used for access control during normal working hours or when the facility is manned. They should never be used to provide physical security for unmanned or part-time facilities. It should be noted that electronic cipher locks should be equipped with backup battery power to permit access during power outages.

30.3 Dial combination locks. This type lock is generally used on doors inside the facility and not on outside entrances. Group I dial combination locks provide a high degree of physical security and may be used when the facility is unmanned. This type lock is frequently used with a cipher lock. During the time that a facility is manned, the dial lock may remain open. Access would be controlled by the cipher lock.

30.4 Internally controlled electric door release. This type of access control may be used internally if access to the entire facility is controlled. Access authorization must be verified when using this method. This may be done by using a guard inside an entrance to the controlled area to properly identify personnel.

40. Perimeter fencing. Perimeter fences may provide a high degree of access control. The distance from the facility that a fence is installed is dependent on the available real estate and the need for facility protection. The distance should be great enough to permit detection, prior to reaching the facilities, of personnel who have successfully penetrated the perimeter barrier. Chainlink fences are recommended and may be extended by installing three strands of barbed wire atop the fence. Fences should be a minimum of 8 feet high without barbed wire. All fence posts should be securely anchored in concrete to prevent removal or the fence being easily pushed over. All gates should be equipped with locking mechanisms and remain secured when not in use. Personnel access gates may be equipped with cipher locks but should have other locking mechanisms such as padlocks for periods of time when the facility is unmanned.

50. Perimeter lighting. The major function of perimeter lighting is to provide visibility of the area surrounding the facility during hours of darkness. When properly installed, lights may also be effective as a deterrent to attempted barrier penetration. It is important when designing a perimeter lighting system to use lights with rapid turn-on time and recovery time after power outages.

50.1 Types of perimeter lights. Among the types which may be used are incandescent, mercury vapor, Fluorescent, tungsten-halogen, metal halide, high pressure sodium, and low pressure sodium.

TABLE C-1. Comparison of perimeter lighting types.

Lamp type	Lamp efficacy (Lumens per Watt)	Life (hours)
Incandescent	9-22	750-2,500
Fluorescent	45-95	7,500-20,000
Metal halide	80-115	7,500-15,000
High-pressure sodium	80-140	12,000-24,000

50.2 Installation practices. Exterior perimeter lighting may be installed by using direct or indlrect illumination. Lights should be installed on or ‘near the roof of the structure and should be positioned to provide total coverage of the areas surrounding the facility. If the lights are not adequate for providing light beyond the perimeter fence, if installed, lights should be installed on poles at the fence line to provide illumination for an adequate distance beyond the perimeter barrier. A safe distance may be defined as a minimum of 15 feet, but may be greater, depending on the terrain and threat of penetration. Indirect lighting involves installing lights away from the structure, pointing toward it. This will provide backlighting to easily detect intruders. If it is necessary to provide lighting beyond the perimeter, lights may be installed facing both directions, providing lighting from the perimeter to the facility and external to the perimeter barrier.

60. Closed circuit television (CCTV). This type system may be used for physical security inside and outside the facility. This system is particularly effective for monitoring hallways, doors, and perimeters. The CCTV system consists of a monitor station and cameras installed in strategic locations.

60.1 Monitor station. The monitor station should be located in an area within the facility which is out of the main ersonnel areas and provides adequate accessibility to the area protected by the system. Monitor stations may be configured with one monitor with a mechanism to select one camera at a time for viewing, or they may have a monitor for each camera. In high security facilities, the latter configuration is more effective.

60.2 Cameras. Cameras should be positioned to provide maximum coverage of the area to be monitored. When used to monitor open areas or as perimeter monitors, cameras should be spaced in such a way that the field of view overlaps that of adjacent areas to ensure complete coverage. Cameras should also be installed in a position where tampering is difficult. Additional protection should be provided by installing all power and signal cables for the system in conduit or duct. When cameras are used to monitor exterior perimeters or dimly lighted areas, additional lighting as specified by the manufacturer may be needed.

70. Intrusion detection system (IDS). An intrusion detection system may be used in facilities to provide additional protection. IDSS typically consist of magnetic switches and motion sensors. All exterior entrances, open areas, and sensitive areas within the facility should be protected. Motion sensors may be installed to provide general coverage of open areas to prevent an intruder from crawling under the area of coverage. Areas protected that require only periodic access should be armed at all times except when authorized access is necessary. The IDS should connect to a remoted monitor station through a dedicated line or autodial telephone line. This will aid in providing notification to the appropriate police or security agency. The IDS should be designed as specified in appropriate security documents.

APPENDIX D
CHECKLISTS

10. Scope. This appendix provides checklists for site survey engineering, power-system evaluation, and energy conservation.

20. Applicable documents. This section is not applicable to this appendix.

30. Site survey engineering checklist.

Date: ______________

Name of Facility: __________________________ Location: ________________________

Person(s) completing checklist: ____

Identification

1. Has the facility been completely and accurately identified?

Latitude: ________________ Longitude: ________________ Elevation: ______________

Map Sheet Number: ____

Map Coordinates: _____________________ Nearest City/Town: _____________________

County/State/Country: ____

Weather

2. Has meteorological data for the site location been thoroughly researched? Use of triservice Engineering Weather Data Manual (TM 5-785, NAUFAC P-89, AFM 88-29) is mandatory within DoD.

a. Design temperatures.

(1) Summer dry bulb and wet bulb: _______________________________________

____

(2) Winter dry bulb and wet bulb: _______________________________________

____

b. Humidity conditions.

(1) Relative humidity (typical, by month): ______________________________

____

c. Degree days.

(1) Heating:

(2) Cooling:

d. Precipitation.

(1) Rainfall (by month):

(2) Snowfall (by month):

(3) Ice formation (by month):

(4) Damaging hail potential (by month):

e. Prevailing winds.

(1) Direction (by month):

(2) Speed (by month):

f. Solar radiation.

(1) Solar angle (by month):

(2) Average daily hours of sunshine (by month):

(3) Average intensity (Btu/hr x ft^2 or W/m^2) (by month):

g. Lightning.

(1) Density (by month):

(2) Unusual weather potential (monsoon, tornado, hurricane, sand storm) (by month):

Geographical features.

3. Have important local geographical features which could affect building siting and design been identified and analyzed?

a. Hills and mountains (as they affect weather, winds, and solar radiation): ____________________

b. Bodies of water (as they affect weather, provide floor potential, provide potable source, serve as heat sources or sinks): ____________________

c. Vegetation (as it provides soil erosion protection, wind screening, blocking of solar radiation): ____________________

d. Seismic activity: ____________________

e. Vulnerability (as created by proximity to target areas, dangerous activities, hazardous materials, or other risks): ____________________

f. Soil conditions: Has local soil been tested for construction, chemical,and electrical properties? ____________________

On-site support.

4. Have on-site support capabilities been determined?

a. Power capability and reliability: see volume II, item 40, power checklist: ______

b. Other utilities.

(1) Water supply (quality and quantity): ______

(2) Sewage disposal: ______

(3) Centralized heating/cooling plant: ______

(4) Natural gas: ______

c. Maintenance.

(1) Mission (other information systems activities which have repair and testing facilities): ______

(2) Support (other DoD activities which have maintenance capabilities): ______

d. Communications.

(1) Voice (access to military and civilian networks):

(2) Data (access to military and civilian networks):

e. Transportation.

(1) Air:

(2) Ground:

(3) Sea:

f. Supply.

(1) parts/materials:

(2) Storage:

g. Housing.

(1) Dormitory:

(2) Family:

(3) Transient:

h. Food service.

(1) Types (dining halls, cafeterias, fast food, etc.):

(2) Capacities:

(3) Operating hours (24 hrs for shift workers):

i. Administration:

j. Personnel services:

k. Medical and dental:

(1) Hospital (no. of beds, types of clinics, dependent care):

(2) Clinic (no. of beds, types of services, dependent care):

5. Off-site support.

a. power sources (capacity/reliability):

b. Other utilities.

(1) Water supply (quality and quantity):

(2) Sewage disposal:

(3) Natural gas:

c. Maintenance and services.

(1) Communications repair and parts:

(2) Data processing repair and parts:

(3) Other types of repair and parts:

d. Communications.

(1) Voice (access to networks): ______________________________

____

(2) Data (access to networks): ______________________________

____

e. Labor sources.

(1) Construction: ______________________________

(2) Other skilled: ______________________________

(3) Manual: ______________________________

f. Transportation.

(1) Access roads (condition and capacity): ______________________________

____

(2) Air (proximity of airport): ______________________________

____

(3) Ground (road and rail): ______________________________

____

(4) Sea (proximity of port facility): ______________________________

____

g. Energy and fuel sources.

(1) Coal : ______________________________

(2) Oil : ______________________________

(3) Natural gas: ______________________________

(4) Geothermal : ______________________________

(5) Solar: ______________________________

h. Housing.

(1) Houses: ______________________________

(2) Apartments: ______________________________

i. Food service.

(1) Restaurants (type and hours of operation): ______________________________

____

(2) Fast foods (type and hours of operation): ______________________________

____

j. Recreational facilities:

____

____

k. Local standards, laws, and customs (as they influence the operation of a DoD facility).

(1) Construction practices and standards: ______________________________

____

(2) Social customs: ______________________________

____

(3) Geopolitical considerations: ______________________________

____

(4) Other considerations: ______________________________

____

40. Power system checklist.

1. Name, address, and telephone number of power supplier: ____________________

____

2. Location of power generating plant: ____

____

3. Location of nearest substation: ____

____

4. Available power: Voltage: ____________________ Frequency: ________________

5. Method of power distribution: Overhead Underground

6. Is available power adequate? Yes No

7. Will a dedicated transformer(s) be required? Yes No

8. Will transient voltage protection be incorporated into the power company switch gear at the facility entrance? Yes No

9. If transient suppressors are to be installed, will they be between the-power transformer and switch gear? Yes No

10. Is the backup power required? Yes No

11. If backup power is required, what types of systems will be used?

____

____

12. Will frequency conversion be required to power fixed or mobile DoD equipment? Yes No

13. have tests been conducted to determine soil resistivity and conductivity? Yes No

14. What facility grounding method will be used? ______________________________

____

15. Will air terminals (lightning rods) be used for lightning protection? Yes No

16.. Will dedicated Dower panels and isolated ground outlets be used for sensitive electronic equipment? Yes No

17. Will facility transient suppressors be installed? Yes No

18. What type of suppression devices will be used? ____________________

____

19. Where will the suppression devices be installed? ____________________

____

20. Will facility powerline filters be required? Yes No

21. Are transient protectors built into equipment which will be operated in the facility? Yes No

22. Will equipment be used in the facility that may generate transients which could affect other equipment? Yes No

23. Will isolation transformers be used in areas where sensitive electronic equipment is installed? Yes No

24. Are other power subscribers nearby which may generate powerline transients? Yes No

25. What is planned to reduce or eliminate the effect of these transients?

____

____

26. Is the facility in an area of high lightning activity? Yes No

27. What is the frequency of electrical storms in the area? ____________________

____

28. Will equipment be installed which requires dc voltage? Yes No

29. What dc voltages are required? ____________________

____

30. What method will be used to supply dc voltages?

a. Rectifier/chargers and batteries b. Rectifiers
c. Dc generators d. Converters

31. Will dc-to-dc converters be used? Yes No

32. Will emergency backup power be required? Yes No

33. What type of emergency conversion will be used?

a. Static UPS b. Rotary UPS Battery c. Alternative power source

34. If a battery room is used, have adequate safety measures been considered? Yes No

35. Will only mission essential equipment be used while power is being supplied by backup systems? Yes No

3b. How long must operation be sustained when power is being supplied by backup systems?____________________________________

37. Will the backup power system provide for sustained operations as required? Yes No

50. Energy conservation checklist for environmental control.

1. General information.

a. Do site survey data include complete information on local weather conditions?____________________

b. Do site survey data include useful information concerning site features which can affect energy consumption?____________________

c. Have the appropriate design conditions been used to determine the types and sizes of environmental control equipment?____________________

d. Will environmentally sensitive electronic areas, such as computer rooms, be provided with dedicated and backup HVAC systems?____________________

e. Has an energy management program been established for the facility?____________________

2. Heating system.

a. Have all heating requirements been included in heating load calculations?____________________

b. Has use of an economical and available fuel source been considered in the selection of heating equipment?____________________

c. Have fuel efficiency, heat recovery applications, and other energy-saving techniques been considered in the design of the heating system?

d. Will forced-air ductwork or hot water piping be properly insulated?

e. Will forced-air ductwork and hot water piping be provided with the necessary dampers and valves, respectively, to balance and control flow rates?

f. Has a reasonable growth potential been incorporated into the heating system design?

3. Cooling system.

a. have all cooling requirements been included in cooling load calculations?

b. Where acceptable, has energy-efficient cooling equipment been selected?

c. Has the cooling equipment been matched to the characteristics of the total cooling load (sensible cooling versus latent cooling)?

d. Have energy-efficient techniques such as economizer cycles, off-peak operating cycles, and VAV systems been considered in the design?

e. Has a reasonable growth potential been incorporated into the cooling system design?

4. Solar energy.

a. Does the architectural design of the facility consider the control and application of solar radiation?

b. Will solar energy be applied for building heating and cooling?

c. Has daylighting been considered in building design?

d. Will solar energy be used to produce hot water?

5. Construction.

a. Will the construction materials and techniques used produce a tight building, which minimizes unwanted heat gains and losses?

b. Will the building be properly insulated, to reduce heating and cooling loads?____

____

c. If building is hardened, will the potential environmental control advantages be exploited?__________________________________

____

d. Will sensitive electronic areas, such as computer rooms, be configured and operated so that the indoor environmental conditions can be maintained without excessive operation of HVAC equipment?__________________________

____

____

DESIGN CONCEPT FOR AN EFFICIENT SMALL FACILITY

10. Scope. This appendix shows an earth-sheltered design concept that could be applied to small DoD electronics facilities in all but artic locations. It is a facility that can be operated unattended or attended. Although glass is used extensively for heating, cooling and daylighting, the structure is relatively invulnerable to functional damage by weather, vandalism, or terrorism.

20. Applicable documents. This section is not applicable to this appendix.

30. Definitions. See section 3.1 of

40. Design features.

40.1 Site selection. An earth-sheltered building. such as depicted in figure E-1, can be built on any terrain. Although preferred, it is not necessary to use a south-sloping (Northern hemisphere) hill for an earth-sheltered building. It can be constructed on level ground and the physical and economic benefits obtained by earth berming. With either type of site, a swale is required behind the structure to obtain necessary drainage. Core samples should be taken at any prospective site to determine exact soil conditions.

40.2 Advantages. The advantages of an earth-sheltered building are:

a. Physical security - weather, fires, and vandals are not likely to damage a building of poured concrete with earth cover on three sides and the top. The lower profile and basic construction methods afford some blast resistance. Nuclear radiation effects can easily be reduced by a factor of 50 to 1000.

b. Less problems with EMI and noise - the effects of EMI from external sources is reduced by the surrounding earth; a facility ring ground can be easily located at a depth where the soil will remain moist and highly conductive. Audible noise control at facilities near runways or highways is vastly improved with earth-sheltered construction.

Lower cost heating and cooling - several feet of earth cover make it possible to heat and cool the facility for a small fraction of the cost for an above-ground structure. Exterior maintenance costs are greatly reduced as well as the chance of structural damage due to wind.

40.3 Theory of operation - winter. The addition of a Trombe wall a few inches behind the south-facing windows vastly improves security and offers a method to furnish most of the required heating. Trombe walls are usually 6 or more inches thick and made of poured concrete. Small slots (vents) with specific dimensions are used to control the heating cycle as shown in figures E-2a and b. As expected, if the glazing is damaged from any cause,

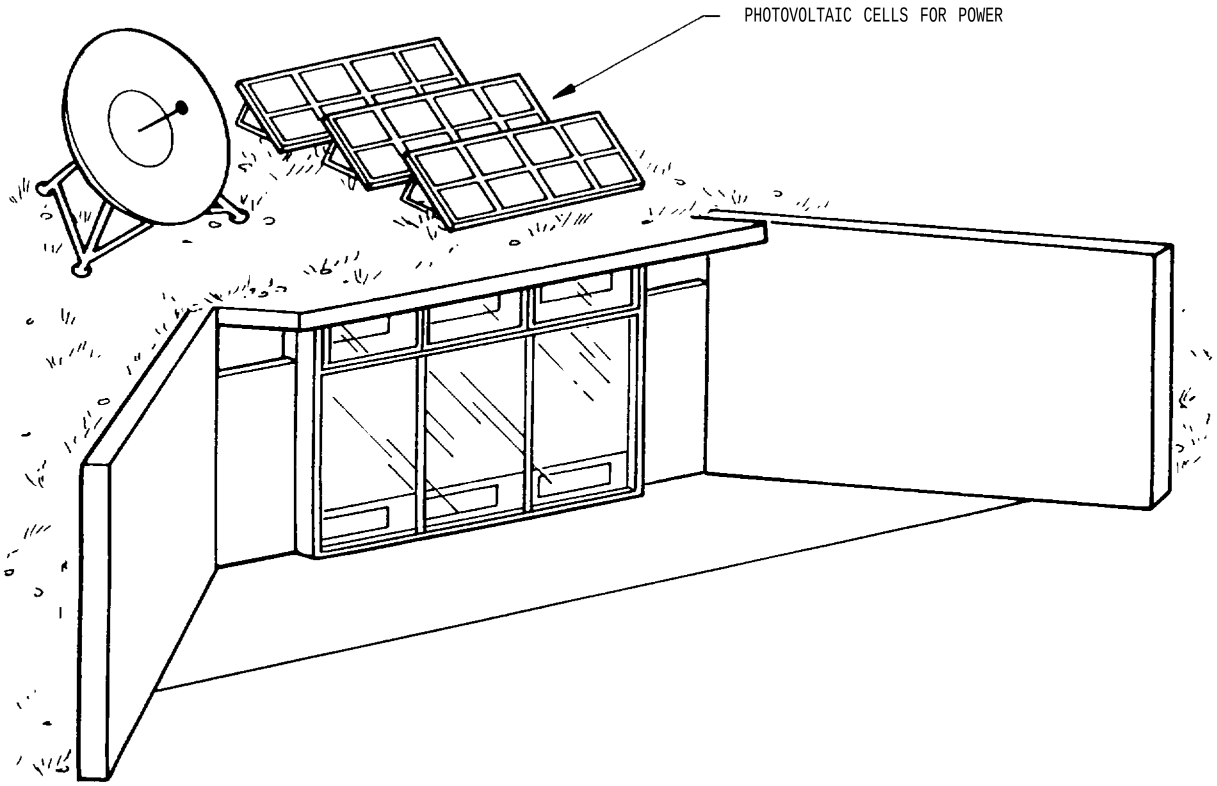
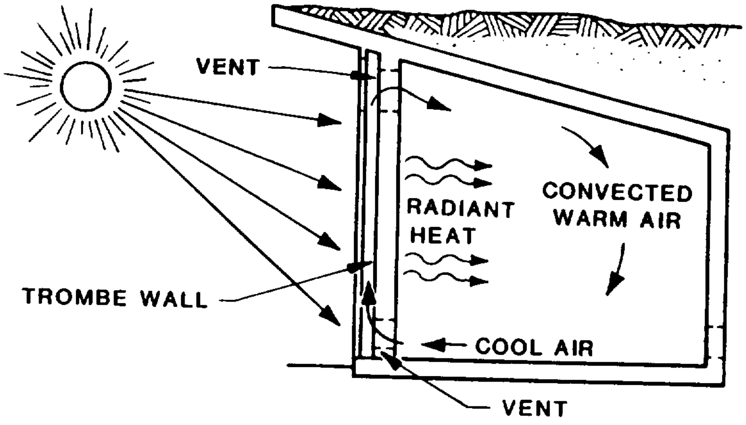
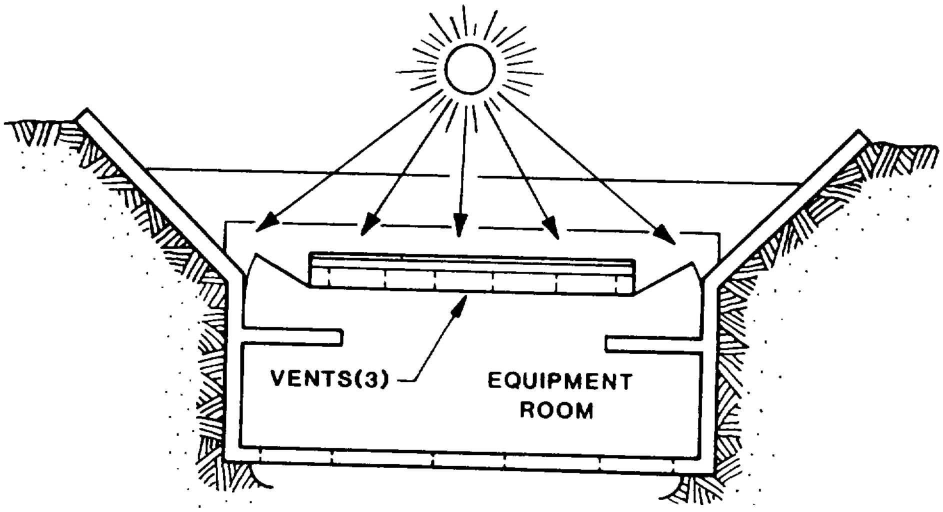


FIGURE E-1. Earth-sheltered building.



A.



PLAN VIEW

B.

FIGURE E-2. Winter operation.

some of the natural heating will be temporarily disrupted, but access to the building by unauthorized personnel continues to be denied. The small slots in the Trombe wall can also be covered with expanded metal to prevent access to the interior by tossed objects. Heating with a Trombe wall is classed as indirect gain, where solar energy is absorbed on the outer surface of a masonry wall, but transfer through the wall is delayed. Properly designed, the outer surface of a glazed concrete wall gets very hot during the day and the heat penetrates the wall and warms the inside of the structure after sunset. This arrangement also pulls cooler air from the floor (figure E-2a and b) through the lower vents and across the hot surface between the glass and concrete. This rising column of air is heated by thermosiphon action and returned to the room. At night, the lower vents automatically close to prevent loss of building heat.

40.4 Theory of operation - summer. In summer, the Trombe wall is used to provide cooling figure L-3, a and b). The structure roof overhang is carefully sized (based on latitude) to reduce the amount of solar radiation impacting the outer surface of the wall during the summer months. The upper Trombe wall vents are opened to the outside and rear floor level vents are opened to accept air from a cool tube. Cool tubes have typical dimensions of 8 inches (20 cm) in diameter and 100 feet (30 m) in length, and are buried at the constant-temperature level of the particular geographic location. The warm, front surface of the Trombe wall pulls the cool air from the floor and exhausts it between the glass and the wall, and outside through the open top vents. The usual application of media filters will be required to control dust and other particulate. In high humidity areas, it may be necessary to provide a dry sump at the bottom of the vertical portion of the cool tube.

40.5 Limitations on using natural heating and cooling. As expected, equipment that requires precise control of humidity and temperature is not a good candidate for installation in an earth-sheltered structure that uses only natural heating and cooling. But if conventional heating and cooling systems are used, all other advantages of earth-sheltering apply.

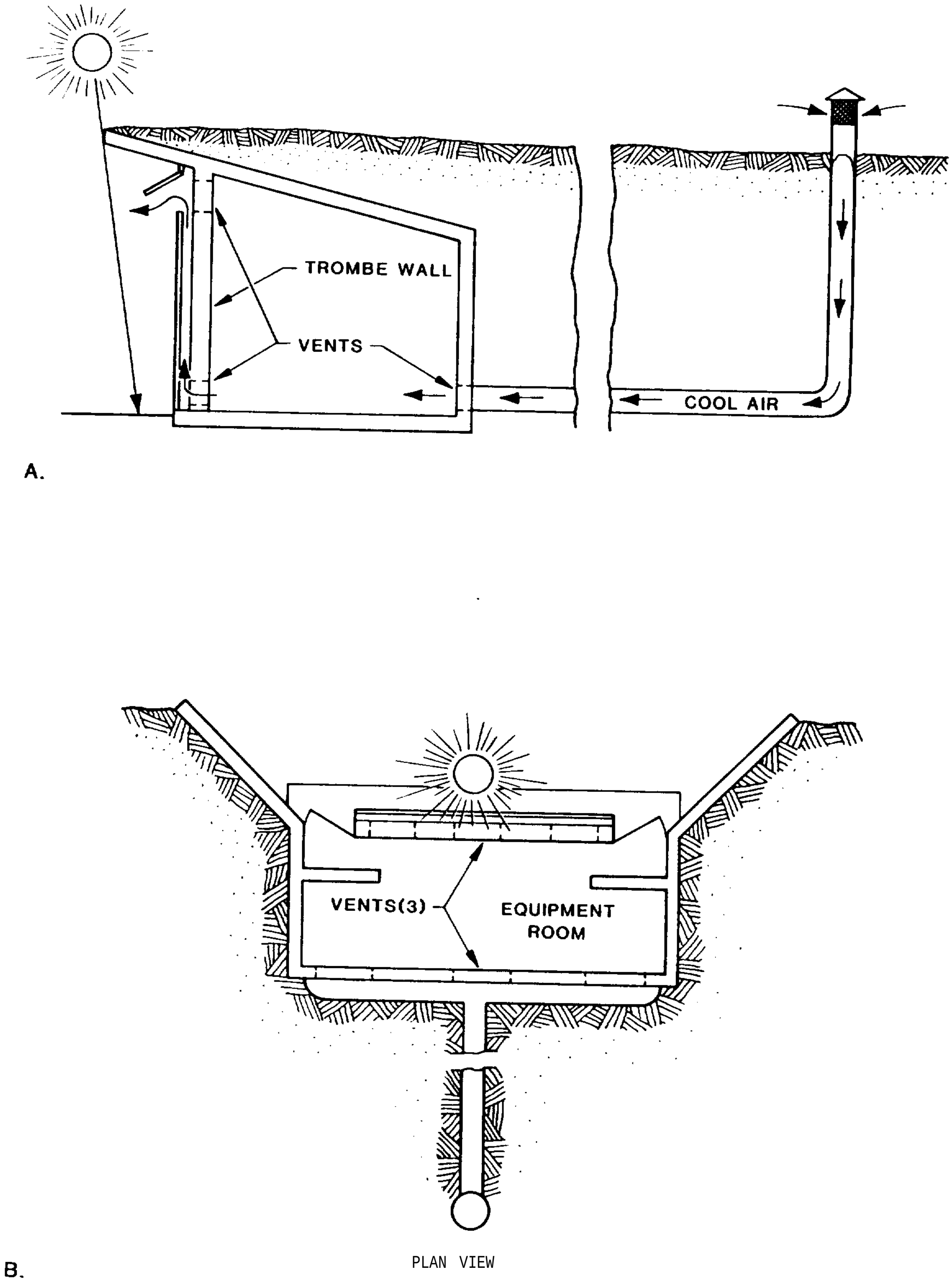


FIGURE E-3. Summer operation.

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*U.S. GOVERNMENT PRINTING OFFICE: 1990--504-034/50045

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