CHAPTER SUMMARIES

Chapter 1: Design Process

Summary: This chapter addresses the design process, during which mechanical and electrical systems and equipment are considered, selected, evaluated, sized, and integrated into a building. The design process includes identifiable phases, generally termed pre-design, conceptual design, schematic design, and design development. The construction and occupancy and operations phases follow design. Building commissioning is an emerging process being used to provide quality assurance to the design and construction endeavors.

Design intent and design criteria are emphasized as critical to successful design. Design hypotheses must be validated through analysis, using a range of methods and tools. Built projects can be assessed using post occupancy evaluation techniques. Case studies are being used both as examples and as a framework for building evaluation. The influence of codes and standards, and costs (first and life-cycle) is discussed.

Passive, active, and hybrid solutions to design problems may be implemented. The differences between energy-efficient, green, sustainable, and regenerative design are explored. A philosophy of design espoused by John Lyle is summarized; this philosophy suggests:

Letting nature do the work,
Considering nature as a model and as a context
Using aggregating solutions rather than isolated solutions
Matching technology to the need at hand
Seeking common solutions to disparate problems
Shaping the form of systems and buildings to guide the flow
Shaping the form of systems and buildings to manifest the process
Using information to replace power
Providing for multiple pathways, and
Managing storage to match needs with resources.

The Gilman Ordway Campus of the Woods Hole Research Center in Falmouth, Massachusetts is provided as a case study of design process for a green project.

Chapter Outline

1.1 Introduction
1.2 Design Intent
1.3 Design Criteria
1.4 Methods and Tools
1.5 Validation and Evaluation
- (a) Conventional validation/evaluation approaches
- (b) Commissioning
- (c) Case studies

1.6 Influences on the Design Process
- (a) Codes and standards
- (b) Costs
- (c) Passive and active approaches
- (d) Energy efficiency
- (e) Green building design strategies
- (f) Design strategies for sustainability
- (g) Regenerative design strategies

1.7 A Philosophy of Design

(a) Let nature do the work
(b) Consider nature as both model and context
(c) Aggregate rather than isolate
(d) Match technology to the need
(e) Seek common solutions to disparate problems
(f) Shape the form to guide the flow
(g) Shape the form to manifest the process
(h) Use information to replace power
(i) Provide multiple pathways
(j) Manage storage

1.8 Case Study: Design Process (Woods Hole Research Center)
References

Key Concepts

- The Absolutely Constant Incontestably Stable Architectural Values Scale (intriguing)
- design process (a multi-stage flow of information, ideas and decisions)
- design values (as critical to intentional design)
- design intent (as the starting point for design solutions)
- design criteria (as benchmarks for design intent)
- design validations (as critical to good design outcomes)
- design process influences (codes/standards, first costs/life-cycle costs)
- building evaluation (as a learning and verification process)
- post-occupancy evaluation (POE)
- case studies (as an emerging design tool)
- passive/active design approaches (as fundamental options)
- energy efficient vs. green vs. sustainable vs. regenerative design (important to distinguish)
- John Lyle design philosophy (as worth of consideration)
- Woods Hole Research Center, Gilman Ordway campus (a green building example)
- AIA/COTE Top Ten Green Projects Award

Chapter 2: Environmental Resources

Summary: This chapter looks at the design of a building and its systems in the contexts of site-based forces, global forces (such as population, water, energy, and materials resources), and time. Sustainability—living on a fixed budget of renewable energy, water, and material resources—is seen as a necessary long-term goal that should be addressed by today's design decisions.

The evolution of energy resources over time is noted along with the evolution of buildings as they adapted to changing energy resources. Renewable and non-renewable energy sources are discussed, with particular emphasis on electricity because of its importance to building design. The primary sources and end uses of the United States' energy supply are presented. Water is addressed as a resource that may well become a limit to growth in many communities. Sources and uses of water are considered and opportunities for conservation suggested.

Sources of building materials are discussed along with their implications. Example projects that address appropriate building materials are presented. Embodied energy and options for reuse and recycling of materials are addressed.

Challenges facing today's building designers—in the transitional period leading to an emphasis upon renewable material, energy, and water resources—are discussed. These challenges include: design for recycling, design for energy transition, design for information exchange, and design that considers the effects of/on transportation.

The chapter concludes by asking: How are we doing? The concept of environmental footprint is advanced as a way of answering such a complex question. The evolution in much of Europe from designing to minimize energy usage to designing to minimize carbon emissions is noted as an important transition in thinking. The Philip Merrill Environmental Center of the Chesapeake Bay Foundation is presented as a case study of design process with energy, water, and materials in mind.

Chapter Outline

2.1 Introduction
2.2 Energy
2.3 Water
2.4 Materials
 (a) Embodied energy
 (b) Recycled or virgin material
2.5 Design Challenges
 (a) Design for building recycling
 (b) Design for energy transition
 (c) Design for the information age
 (d) Design for transportation
2.6 How Are We Doing?
2.7 Case Study: Design Process and Environmental Resources (Chesapeake Bay Foundation)
References

Key Concepts

- population growth (as a driver for the use of renewables and improved resource efficiency)
- the First and Second Laws of Thermodynamics (as influences on building design)
- entropy (as lurking behind all building design decisions)
- building (as a consumer of resources and energy)
- renewable and non-renewable energy options (as options for many building systems)

- dependence upon non-renewable energy sources (current status, not sustainable)
- building reliance upon electricity as an energy source (current status, not sustainable)
- water (as a looming environmental concern)
- building material sources (as a design concern)
- embodied energy (as a design concern)
- reuse and recycling (as design methods)
- challenges facing today's building designers (as a result of population growth and resource use)
- flexibility (as a means of prolonging building life and usefulness)
- design for disassembly/demounting of parts (as a means of providing flexibility)
- a return to renewable and sustainable energy sources (as a design strategy)
- a link between renewable materials/energy and sustainability (as a design philosophy)
- "low-tech" versus "high-tech" process (as a design consideration)
- information systems (as they influence the design and operation of buildings)
- environmental footprint (as a measure of sustainability)
- Philip Merrill Center (as an example of green design)

Chapter 3: Sites and Resources

Summary: This chapter looks at the interactions that occur between sites and climate, with a focus upon microclimates and site resources. Early decisions related to site planning can have substantial influence on later design phases and resulting building performance. There are a number of site characteristics that interact in a variety of ways with climate elements. Viewing the site as a provider of resources is encouraged.

The climate at a specific site (or portion of a given site) can be substantively different than the climate described by regional climate data (such as for Chicago or Miami). This local climate is termed a microclimate. The conditions in cities, influenced by the urban heat island effect, are given as an illustration of microclimate modifications. Concentrated heat sources, permeable surfaces, channeling of wind, and shading and reflection of solar radiation are drivers for urban microclimates.

Site analysis is promoted as a means of recognizing the resources provided by a site and suggesting ways to bring such resources into the design process. In addition, such analyses can assist in selecting appropriate areas of a site for a project under consideration. Horizontal and vertical views of the site should be addressed during analysis. Considering "layers" of the site is a convenient way to include the vertical dimension. Specific site conditions can be linked to the general design strategies identified in Chapter 4.

The "solar envelope" concept can be used to identify positive and negative implications of a proposed design relative to solar access. Sunpath diagrams (Chapter 6) are an important and useful design tool. Both graphic and model techniques can be used to test design concepts against solar access expectations. Many templates for graphic and model analysis are readily available.

The air on and around a site acts as a conveyor of noise, potential bearer of pollutants, and a resource for ventilation and cooling. Site design can be an effective means of controlling unwanted sounds through absorption, reflection, and masking. Buildings contribute to, and must also respond to, ambient air pollution and larger-scale problems such as global warming. Wind can be used for ventilation (providing fresh air) and for cooling, but can also result in discomfort. Site design can help capture or block wind, as desired.

Site analysis and design are emphasized as critical to appropriate handling of rainfall, runoff, and groundwater replenishment. Surface water on site can be an effective design element and heat sink for passive cooling. Likewise, groundwater can often be used as a heat source or sink. Plants may be used to temper temperature extremes, provide shade, filter daylight, and channel or block wind.

Chapter Outline

3.1 Climates
3.2 Climates within Climates
3.3 Buildings and Sites
3.4 Analyzing the Site
3.5 Site Design Strategies
3.6 Direct Sun and Daylight
- (a) Access to light and sun
- (b) Charting the sun
- (c) The "band of sun"
- (d) Skylines and winter sun
- (e) Sun and shadows: model techniques
- (f) Controlling solar reflections

3.7 Sound and Airflow

Key Concepts

- microclimate (localized climate conditions, as distinct from macroclimate)
- site (as a provider of resources)
- urban heat islands (as a particular type of microclimate)
- site analysis (as an important design tool)
- site layers (analyzing a site both horizontally and vertically)
- Solar Hemicycle (as an example of effective site analysis and design)
- solar (and) daylight access (ensuring accessibility to resources)
- solar envelope (portion of site, both horizontally and vertically, with solar access)
- sunpath diagram (provides graphic information on solar position)
- "band of sun" (as a solar utilization tool)
- skyline plots (maps of solar obstructions on and around a site)
- sunpeg shadow plots (using models as a design tool)
- noise (unwanted sound)
- sound shadow (an effect of a sound barrier)
- masking sound (one sound used to hide another)
- greenhouse effect (as a growing concern)
  greenhouse gas
  CFC (chlorofluorcarbon, an important greenhouse gas)
- acid rain (as an after-effect of fossil fuel use)
- ventilation (meaning the introduction of outside air)
- cooling by air motion (as distinct from ventilation)
- deciduous plants (as a climate-sensitive shading device)

Chapter 4: Comfort and Design Strategies

Summary: This chapter presents the concept of thermal comfort, an introduction to climate issues and analysis, and the role of buildings as a mediator between climate and comfort. A building is one of three layers that separate our deep body temperature from the conditions in the external environment; our skin and clothing are the other two layers.

Metabolism, changing in magnitude with activity level, generates heat that must be dissipated to the environment for us to remain healthy and comfortable. A number of bodily response mechanisms regulate the flow of heat from the body core to the skin surface. Heat transfer from the skin to the environment can occur via conduction, convection, radiation, and evaporation. Clothing acts as a mediator between the body and the thermal environment.

Thermal comfort is defined as a "feeling of [thermal] well-being" that can be affected by physical (both personal and environmental) and psychological factors. The importance of psychological factors to building design is emphasized. Physical environmental factors include: air temperature, air motion, relative humidity, and surface temperatures (or radiation). Localized comfort effects are described. ASHRAE comfort recommendations (via Standard 55-2004) are reviewed, with a caution that they tend to downplay the psychological factors. Comfort standards (bioclimatic) that may be more applicable to the design of passive buildings are introduced. These standards begin to draw a link between comfort and climate.

Climate is presented as the character of the ambient thermal environment into which a building is placed. Analysis of climate can provide a valuable tool for building design—suggesting how and when a building should modify naturally occurring conditions. Olgyay's timetables of climatic needs are presented and discussed. Basic design strategies for passive cooling and heating are introduced and linked to climate analysis. Passive cooling strategies include: natural ventilation, high-mass construction, high-mass with night ventilation, and evaporative cooling. Passive heating strategies include: direct gain, indirect gain, and isolated gain approaches. Combined heating and cooling strategies—including daylighting as a valuable adjunct to thermal scheming—are discussed in general terms. Visual and acoustical comfort are noted as being much less holistically developed areas of design than thermal comfort.

Chapter Outline

4.1 The Body
- (a) Metabolism
- (b) Heat flow
- (c) Clothing

4.2 Thermal Comfort
- (a) Comfort standards
- (b) Passive building comfort standards
- (c) Localized comfort

4.3 Design Strategies for Cooling
- (a) Natural ventilation cooling
- (b) High-mass cooling
- (c) High-mass cooling with night ventilation
- (d) Evaporative cooling

4.4 Design Strategies for Heating
- (a) Direct gain
- (b) Indirect gain
- (c) Isolated gain

4.5 Combining Strategies
- (a) Daylighting
- (b) Daylighting, Cooling, and Heating

4.6 Visual and Acoustical Comfort

References

Key Concepts

- layers (of thermal isolation or interaction)
- metabolism (as a driver of thermal comfort needs)
- activity level (as a determinant of bodily heat generation)
- bodily heat flow controls (connecting the body's core and skin)
- environmental heat flow mechanisms (connecting the skin and the built environment)
- clothing (as a control layer that mediates between skin and environment)
- thermal comfort (as a desirable condition resulting from building design)
- personal comfort factors (activity, clothing, adaptive behaviors)
- environmental comfort factors (air temperature, relative humidity, air speed, radiant conditions)
- psychological comfort factors (numerous, many controlled or influenced through design)
- comfort standards (as a guide to appropriate design intent and criteria)
- modified comfort standards (appropriate to passive buildings, sustainable design efforts)
- adaptive model of comfort (an evolving view of comfort responses)
- climate (as a picture of the character of a locale's thermal environment)
- climate analysis (as a tool to understand climate and obtain direction for design)
- passive cooling strategies (ventilation, mass, evaporation)
- passive heating strategies (direct, indirect, and isolated gain approaches)
- daylighting (as an important component of passive climate response strategies)
- visual and acoustical comfort (as worthy of consideration as design intents)

Chapter 5: Indoor Air Quality

Summary: This chapter considers indoor air quality and the many factors that can improve or decrease air quality in buildings. Tighter buildings, the introduction of more and more chemicals in materials and furnishings, and the fact that people spend more and more time indoors have served to bring public attention to indoor air quality (IAQ) problems and solutions. Sick building syndrome is an unfortunately common result of lack of attention to air quality. Multiple chemical sensitivity (or environmental illness) is a much less common, but more debilitating, condition. Designing for appropriate IAQ is not an easy task—as predicting air quality and occupant responses is difficult. Fanger has proposed a methodology and measurement units to assist in this process.

Four major approaches to improve the quality of air within buildings exist: limiting pollutants at the source; isolating pollutants when they are unavoidably generated; filtering air and introducing adequate fresh air; and properly maintaining a building and its equipment. The building designer can play a role in all of these approaches.

Indoor air pollutants can be categorized by type of contaminant (gaseous, organic, or particulate) and by type of effect (odor, irritation, or toxicity). Odors are a simple indicator of air quality problems as people are quite sensitive to odors. Odor sources, however, are typically difficult to isolate in many building occupancies. Carbon dioxide concentrations are often used as an air quality indicator in spaces with normal occupant loadings. Irritants are normally not detected by occupants, but may cause increasing distress over time and with continuing exposure. Toxic substances, often particulates, can cause severe health problems with continuing exposure and sufficient concentrations.

Common indoor air pollutants include odors, carbon dioxide, carbon monoxide, a wide range of particulates, volatile organic compounds, ozone, tobacco smoke, biological contaminants, radon, and others. Sources of such pollutants include building occupants, interior finishes and furnishings, and building and consumer equipment and processes. The link between indoor air quality and health is discussed in the context of green building design and chemical sensitivity.

Site planning and zoning of a building to help control indoor air quality are recommended. Ventilation, both mechanical and passive, is a common control technique (usually mandated by codes). Exhaust of contaminants is another common technique. Numerous strategies and examples of passive ventilation are presented. A wide range of equipment for IAQ management is discussed, including filters, exhaust fans, makeup air units, heat exchangers (of several types), desiccant and refrigerant dehumidifiers, ultraviolet radiation lamps, unit air cleaners, and IAQ controls. Proper location of such equipment is discussed.

Chapter Outline

(c) Underslab ventilation
(d) Preheating ventilation air

5.6 Equipment for Control of IAQ
(a) Exhaust fans
(b) Heating/cooling of makeup air
(c) Heat exchangers
(d) Desiccant cooling
(e) Task dehumidification and humidification
(f) Filters
(g) Locating air-cleaning equipment
(h) Ultraviolet radiation (UV)
(i) Individual space air cleansing
(j) Controls for IAQ

5.7 IAQ, Materials, and Health
(a) Multiple chemical sensitivity
(b) Materials and IAQ
(c) Green design and IAQ

References

Key Concepts

- historic concern for air quality (and resultant building systems)
- trends leading to heightened concern about building air quality
- sick building syndrome (as a result of poor indoor air quality)
- design for indoor air quality (as a difficult task)
- IAQ control strategies (limit sources, isolate sources, filter air, dilute pollutants, maintain building and equipment)
- building commissioning (as a means of ensuring Owner's Project Requirements)
- indoor air pollutants/contaminants (as design concerns)
  - odors (as an indicator of air quality)
  - carbon dioxide (as an indicator of air quality)
  - irritants (as a class of pollutants)
  - volatile organic compounds (VOCs; as a class of pollutants)
  - toxic substances (as a class of pollutants)
  - biological contaminants (as a class of pollutants)
  - radon (a radioactive soil gas)
- outgassing (from building materials)
- moisture (as a catalyst for biological contaminants)
- multiple chemical sensitivity (a condition also known as environmental illness)
- ventilation (as an approach to improve IAQ)
- makeup air (as an approach to improve IAQ)
- replacance (a measure of the effectiveness of air exchange)
- site planning (as a tool for improving building IAQ)
- passive approaches (as an IAQ control strategy)
- stack effect (as a means of inducing air flow)
- filters (particulateBpanel and media; adsorption)
- air washers (as a method for improving IAQ)
- electronic air cleaners (self-charging, charged media, and two-stage)
- ultraviolet radiation (as a biological control means)
- equipment location (as a design issue)
- ASHRAE Standards 62.1 and 62.2 (as IAQ design standards)
- LEED (as a green design guideline impacting IAQ design)

Chapter 6: Solar Geometry and Shading Devices

Summary: This chapter begins by noting the importance of understanding the sun's position to site planning and the design of daylighting systems, passive solar heating systems, and passive and active cooling systems. Solar patterns are an important context for architectural design.

Properties of the sun and its resulting radiation are discussed. The geometric interactions between the sun and the earth during the year are considered. The altitude and azimuth angle are identified as key measures of the sun's position relative to a location on earth and the cyclical pattern of these angles over the course of a year are presented. The critical distinction between clock time and solar time is noted; the clock time oddity of Daylight Saving Time is discussed. The difference between true (solar) south and magnetic south is flagged. Various types of sunpath projections are presented and their application to design situations discussed. These include sunpeg diagrams and horizontal and vertical projection sun path diagrams.

Shading is addressed in some detail. Fixed shading optimized for orientation and movable shading devices are considered. Numerous diagrams and built examples of shading devices are presented. Shadow angles and shading masks are introduced as design tools to assist in the design of shading devices. An analysis of a horizontal shading device is included. Various design approaches for shading devices are considered.

Chapter Outline

6.1 The Sun and Its Position
- (a) Earth's rotation and tilt
- (b) Altitude and azimuth

6.2 Solar versus Clock Time
6.3 True South and Magnetic Deviation
6.4 Sunpath Projections
6.5 Shading
- (a) Shading for orientation
- (b) Operable shading devices

6.6 Shadow Angles and Shading Masks
- (a) Shadow angles
- (b) Shading masks
- (c) Use of shading masks
- (d) Designing finite horizontal shading devices
- (e) Design approaches

References

Key Concepts

- solar insolation (as a sometimes resource and unwanted burden)
- solar position (as ways of relating the sun's location relative to objects on Earth)
- solar versus clock time (as critical to the use of sunpath diagrams)
- solar versus magnetic south (as critical to the use of sunpath diagrams)
- types of sunpath projections (as defining the form of these diagrams)
- shading devices (as a design method)
- shading masks (as a design tool)
- physical models (as a design tool)

Chapter 7: Heat Flow

Summary: This chapter examines heat flow into and out of a building through the various components of the building envelope and via ventilation or infiltration air flow. All elements of the envelope are considered: walls, roofs, floors, windows, and doors. All elements of sensible heat flow are considered (convection, conduction, and radiation) along with latent heat flow.

The building envelope is described as a transition space where indoor and outdoor conditions interact. Time is a critical dimension for building envelope performance; the envelope can serve to illustrate this dimension for building users and observers through its design.

Envelope design decisions are crucial to the success of sustainable design efforts. Design intent with respect to envelope elements is a key consideration. Norberg-Schulz has identified four key functional elements (relative to intent): connector, barrier, filter, and switch. The concept of envelope as transformer is also introduced. The performance of an envelope component vis-a-vis these intents will vary with the nature of the force (wind, radiation, rain) being considered. These functions may be addressed in the context of open frame and closed shell approaches to envelope design. Switches are celebrated as a way for the building designer to inform and involve occupants in building performance. Thermal sailing, occupants tuning the operation of a passive building, is given as one example of the intrigue of switches.

Heat flow through the building envelope varies with weather (seasons) and the nature of the envelope component (opaque, fenestration, ground-contact). Sensible heat flow is typically most important and involves conduction, convection, and radiation. Heat flow through solids can be predicted using the thermal properties of conductivity or conductance, and their inverse—thermal resistance. Conductor materials are sometimes desirable (as in passive solar gain systems), but insulators are more commonly used in envelopes. There is a range of insulation materials, forms, and applications for the designer to choose from. Although conceptually different from heat flow through solids, conductance, resistance (and emittance) are also used to characterize heat flow through air. Static and dynamic approaches to the analysis of envelope heat flow are contrasted.

The effects of air and vapor flow through the building envelope are addressed. Water vapor flows from the high-pressure side of the envelope to the low-pressure side. If water vapor condenses within the envelope, material damage and air quality problems may result. Properly placed vapor retarders need to be considered during envelope design. Air may flow through the envelope unintentionally through cracks and gaps (infiltration) or intentionally through openings or ducts (ventilation). Such air flow will contribute (perhaps substantially) to building heat gain and loss. Means of estimating infiltration and establishing ventilation air flows are presented.

Calculations of heat flow through the building envelope are commonly used to size heating and cooling systems. The heat flow through opaque portions of the envelope is generally a function of the thermal properties of the envelope, the area of the envelope, and the temperature difference across the envelope. U-factor characterizes the thermal performance of an envelope assembly (as opposed to an individual element such as siding or insulation). Past and future trends in envelope thermal performance are discussed. Windows have seen the most dramatic recent changes in performance and in thermal rating metrics; wall and roof technologies have also seen advancements. Example calculations of opaque envelope heat flow are provided. Thermal gradient calculations (useful to predict condensation) are discussed. Windows and skylights are given special consideration because they are still commonly “weak links” in a thermal envelope, they can account for a substantial portion of infiltration, and they also admit solar radiation to a building.

Window performance indicators (including U-factor, solar heat gain coefficient, visible transmittance, and air leakage) are presented. Performance-enhancing fenestration features—such as low-ε coatings, inert gas fills, and selective transmission films—are discussed. The concept of the “superwindow” is introduced. Shading devices and approaches are discussed.

The chapter concludes with an introduction to the fundamentals of design heat loss and heat gain calculations. The physical basis of such losses and gains is presented via commonly encountered equations used in the hand calculation of building thermal loads. Opportunities for reducing such loads are outlined and the impact of envelope thermal standards considered.

Chapter Outline

7.1 The Building Envelope
7.2 Building Envelope Design Intentions
7.3 Sensible Heat Flow through Opaque Walls and Roofs
    (a) Static versus dynamic: sensible versus latent
    (b) Heat flow processes
    (c) Thermal properties of components
    (d) Thermal classifications of materials
    (e) Composite thermal performance
    (f) Special envelope heat flow conditions
    (g) Predicting surface temperatures and condensation
    (h) Dynamic thermal effects
7.4 Latent Heat Flow through the Opaque Envelope
    (a) Moisture control fundamentals
    (b) Cold climate moisture control
    (c) Hot, humid climate moisture control
7.5 Heat Flow through Transparent/Translucent Elements
    (a) U-factor
    (b) Solar heat gain coefficient (SHGC)
    (c) Visible transmittance (VT)
    (d) Air leakage
    (e) Low emittance (low-ε) coatings
    (f) Selective transmission films
    (g) Inert gas in the air gap
    (h) Superwindows
    (i) Shading
7.6 Trends in Envelope Thermal Performance
7.7 Heat Flow via Air Movement
    (a) Infiltration
    (b) Ventilation
7.8 Calculating Envelope Heat Flows
    (a) Design heat loss
    (b) Design heat gain
7.9 Envelope Thermal Design Standards
References

Key Concepts

- building envelope as a transition space (as a design concept)
- time as a fourth dimension for building heat flows (as a potential design concept/focus)
- open frame and closed shell envelope concepts (as design directions)
- envelope intentions (filter, barrier, connector, switch; as basic design descisions)
- switches (as a means of providing occupant control and involvement)
- thermal sailing (user operation of a building to maximize comfort or performance)
- metrics for describing heat flow through solids (conductivity, conductance, and resistance;
- as fundamental to understanding envelope thermal performance)
- general thermal performance of a material (as an insulator or conductor; as a design issue)

- insulation types and materials (numerous; as design options)
- radiant barrier (as an insulation type)
- metrics for describing heat flow through air spaces and films (necessary for communication)
- emittance (as a performance indicator)
- envelope heat flow (considering assemblies versus specific materials)
- U-value (as a fundamental performance indicator)
- trends in envelope thermal performance (of general interest)
- principle of diminishing returns (as a basic thermal design restraint)
- windows and skylights (as special envelope elements)
- heat flow through glazing (via conduction and especially radiation)
- daylight transfer through glazing (as related to but distinct from heat transfer)
- high-performance glazing options and characteristics (as an emerging trend)
- superwindows (as a coming design opportunity)
- vapor flow through the building envelope (as related to but distinct from heat flow)
- condensation (as determined by vapor retarders and material temperatures)
- heat loss and gain due to infiltration and ventilation air flows (as a design consideration)
- infiltration estimation methods (air-change rate, crack method; as analysis tools)

Chapter 8: Designing for Heating and Cooling

Summary: This extensive chapter addresses the preliminary development of heating and cooling system options during schematic design and the further refinement of selected options during design development. In effect, the chapter covers how the problem of heating, cooling, and lighting a building should be organized in the early design stages, provides extensive data resources and examples to structure the preliminary systems analysis process, and more extensive data and examples to move systems analysis into design development. The schematic design of daylighting is included because early design decisions regarding daylighting have such a dramatic impact on heating and cooling loads and approaches. More detailed information regarding HVAC systems and lighting design is provide in subsequent chapters.

Establishing an appropriate design intent for the building type and climate is a crucial first step in climate control system design. Bioclimatic charts and a sense of whether a building will be internal-load dominated or skin-load dominated can help get the process on the right track. Building form, orientation, zoning, opaque envelope elements, and fenestration must all be considered when making decisions regarding appropriate heating, cooling, and daylighting strategies. These three systems will interact and there will almost always be a need for trade-offs between systems. Zoning is especially important as a means of grouping like spaces for thermal and lighting purposes. Understanding space function, schedule, and orientation is the key to successful zoning.

Daylighting design guidelines are given for schematic design. Preliminary daylighting design involves establishing daylighting design intents, daylight factor (DF) criteria for the various building spaces, estimating daylighting system performance, and comparing estimated performance to criteria. Tables and figures to assist in these tasks are provided, along with worked examples of the procedures. Window height and area are key factors in sidelighting approaches. Distribution of daylight should be qualitatively considered; lightshelves and combination toplight/sidelight approaches can improve distribution.

Passive solar heating is presented as a viable design strategy for many building types and climates. The philosophy of “insulate before you insolate” is emphasized. Building heat-loss (winter) design criteria are provided for solar and non-solar buildings. Solar savings fraction is introduced as a measure of passive solar heating system performance. Design criteria for performance of a generic passive solar heating system include “standard” and “superior performance” options. Thermal mass (masonry, water, rock beds, and phase-change materials), mass distribution, and orientation of solar glazing are discussed as design elements. Criteria for roof ponds are also presented. Guidelines for collector area and tilt and thermal storage are also given for active solar heating systems. Data tables and figures and worked examples are provided.

Guidelines or criteria for heat gain (summer) are given, a distinction being made between intentionally “open” (such as naturally ventilated) and “closed” building design approaches. These heat gain criteria are followed by guidelines for preliminary design of a range of passive cooling systems including cross ventilation, stack ventilation, night ventilation of thermal mass, evaporative cooling, cool tower, roof pond, and earth tube approaches. Extensive data tables and figures and worked examples are provided.

Following the presentation of design criteria and preliminary analysis methods, the chapter considers the need to re-integrate building needs and potential daylighting, heating, and cooling solutions. The possibility of conflict between design intent and prescriptive code requirements is mentioned. Tradeoffs between systems are further discussed.

Calculations for design heat loss and design heat gain are explained and illustrated, along with the assumptions underlying these procedures. The use of these calculations to explore opportunities for design improvements and to compare estimated building performance against

established benchmarks is emphasized. Calculations for estimating heating season fuel consumption are presented. The concepts of balance point temperature, degree days, system efficiency, time lag, and temperature swing are introduced. Sensible and latent heat effects are differentiated. Psychrometrics, the psychrometric chart, and psychrometric processes are explained.

The chapter concludes by revisiting all the passive heating and cooling systems previously considered at the schematic design level by expanding upon the specificity and detail of analysis methods. "As building design takes shape, more-detailed information becomes useful." For heating systems, this level of consideration addresses glazing, direct gain systems, sunspaces, trombe walls and water walls, and combination passive heating systems. The load-to-collector (LCR) analysis procedure for annual system performance is explained. The sensitivity of systems to design variations is considered. For cooling systems, design development procedures for cross ventilation, stack ventilation, night ventilation of thermal mass, fan-assisted evaporative cooling, cooltowers, roof ponds, and earth tubes are presented. Detailed data tables and examples are provided throughout.

Chapter Outline

8.1 Organizing the Problem
- (a) Fenestration
- (b) Building form
- (c) Building envelope

8.2 Zoning
8.3 Daylighting Considerations
8.4 Passive Solar Heating Guidelines
- (a) Whole-building heat loss criteria
- (b) Solar savings fraction (SSF)
- (c) Thermal mass
- (d) Orientation
- (e) Roof ponds
- (f) Active solar heating

8.5 Summer Heat Gain Guidelines
8.6 Passive Cooling Guidelines
- (a) Cross-ventilation
- (b) Stack ventilation
- (c) Night ventilation of thermal mass
- (d) Evaporative cooling
- (e) Cooltowers
- (f) Roof ponds
- (g) Earth tubes

8.7 Reintegrating Daylighting, Passive Solar Heating, and Cooling
8.8 Calculating Worst-Hourly Heat Loss
- (a) Maximum hourly loss: sizing conventional heating equipment
- (b) Maximum hourly loss: sizing auxiliary heating for passive solar buildings
- (c) Maximum hourly loss: checking design criteria
- (d) Hourly rates of fuel consumption

8.9 Calculations for Heating-Season Fuel Consumption (Conventional Buildings)
- (a) Balance point temperature
- (b) Degree days (DD)
- (c) Yearly space heating energy

8.10 Passive Solar Heating Performance
- (a) Glazing performance
- (b) Direct-gain (DG) systems
- (c) Sunspaces (SS)
- (d) Trombe walls (TW)

(e) Water walls (WW)
(f) Load collector ratio (LCR) annual performance
(g) Variations on reference systems
(h) Thermal lag through mass walls
(i) Internal temperatures

8.11 Approximate Method for Calculating Heat Gain (Cooling Load)
(a) Gains through roof and walls
(b) Gains through glass
(c) Gains from outdoor air
(d) Gains from people
(e) Gains from lights
(f) Gains from equipment
(g) Latent heat gains

8.12 Psychrometry
(a) Cooling process
(b) Heating process

8.13 Detailed Hourly Heat Gain (Cooling Load) Calculations

8.14 Passive Cooling Calculation Procedures
(a) Cross-ventilation
(b) Stack ventilation
(c) Night ventilation of thermal mass
(d) Fan-assisted evaporative cooling
(e) Cooltowers
(f) Roof pond cooling
(g) Earth tubes
(h) Passive cooling summary

References

Key Concepts

General:

- organizing the design problem (as a starting point for thermal design)
- codes and standards (as setting minimum performance or component requirements)
- key design issues for heating, cooling, daylighting (as they direct design efforts)
- design criterion as a function of building type (conventional or passive)
- zoning (as a design organizer)
- daylighting (as it influences heating and cooling loads)
- internal-load dominated (as a result of building form, function)
- skin-load dominated (as a result of building form, function)
- balance point (and balance point temperature; as a design tool)
- design conditions (as input to calculations)
- tradeoffs (likely a necessary part of design process)
- efficiency (as a system metric and objective)
- system sensitivity (as a design tool)
- thermal lag (a physical phenomenon and design strategy)
- temperature swing (interior air temperature; as a performance indicator)
- sensible heat (involving temperature change)
- latent heat (involving moisture)
- psychrometrics (psychrometric chart and processes; as design tools)

Daylighting:

- daylighting approaches (sidelighting, toplighting; as organizing principles)
- daylight factor (as a design criterion)

Solar Heating:

- “insulate before you insolate” (as a recommendation)

- passive solar heating (direct gain, sunspace, trombe wall, water wall, roof pond)
- effects of solar heating on purchased and total energy quantities (to be understood)
- solar savings fraction (SSF, as a measure of solar performance)
- load collector ratio (LCR, as a relative indicator of system size)
- building load coefficient (BLC; a performance metric)
- thermal mass (masonry, water, rock bed, or phase-change materials; as a system component)
- orientation (as a determinant of building layout and window/collector location)
- active solar heating (as a mechanical system solution)

Passive Cooling:

- passive cooling (ventilation—cross, stack, and of thermal mass, evaporative cooling, cooltower, earth tube, roof pond)
- transparent insulation materials (TIM; an emerging technology)
- coolth (as the conceptual opposite of heat)

Chapter 9: HVAC for Smaller Buildings

Summary: This is the first of two chapters that cover HVAC (heating, ventilating, and air conditioning) systems. The focus of this chapter is smaller buildings (residential and small commercial), with a topic organization that proceeds from the need for such systems, to the systems design process, to component locations and sizes, to descriptions of systems and equipment. Although the book has a clear "bias" toward passive solutions, some climates and building types will require the use of mechanical/electrical systems for climate control. An extensive review of such systems is provided.

A process used to design HVAC systems (including complimentary passive systems) is outlined. The various analysis, selection, and sizing activities are organized by design phase. Schematic design addresses general needs and resources, building envelope potentials, passive system opportunities, and preliminary sizing of active systems. During design development, more specific system design requirements are developed, heating and cooling loads are determined, a system or systems are selected, equipment locations are established, equipment is sized, and the system is laid out. During design finalization (development of construction documents), final systems coordination (mechanical with electrical, structural, plumbing, etc.) occurs and the HVAC system decisions and calculations are verified.

The choice between a local or a central system is one of the earliest design decisions. Advantages and disadvantages of both options are reviewed. Preliminary system sizing is discussed. The concept of a "distribution tree is introduced. Controls as a component of HVAC systems are introduced—including thermostats, building management systems, automation systems, and future trends in controls.

The compression and absorption refrigeration cycles are presented as a means of mechanically developing cooling and heating (via a heat pump). Components of compression refrigeration systems are discussed, including conventional and alternative refrigerants and various types of compressors. The issue of CFCs and their connection to global warming is considered. Components and operation of the absorption refrigeration cycle are presented. The relationship of psychrometrics to cooling process and equipment is addressed.

A number of cooling-only systems are presented along with their typical equipment and applications. Such systems include fans, unit air conditioners, misting and roof spray evaporative cooling systems, and evaporative coolers (direct and indirect). Heating-only systems are similarly covered. Such systems include wood heating devices (fireplaces, stoves, pellet stoves, and masonry heaters), electric resistance heating, gas-fired heaters, ceiling mounted electric heating systems, hot water boilers, baseboard and radiator systems, hydronic radiant panels, and warm air heating systems. System zoning and the wide range of equipment and system efficiency ratings are discussed. Systems that will provide both heating and cooling are considered, with an emphasis on heat pumps (air-to-air, water source, and ground source).

Chapter Outline

9.1 Review of the Need for Mechanical Equipment
9.2 Heating, Ventilating, and Air Conditioning (HVAC): Typical Design Processes
9.3 Equipment Location and Service Distribution
- (a) Central or local?
- (b) Central heating or cooling equipment
- (c) Distribution trees

9.4 Controls for Smaller Building Systems
9.5 Refrigeration Cycles
- (a) Compressive refrigeration
- (b) Alternative refrigerants
- (c) Absorption refrigeration cycle

9.6 Cooling-Only Systems
- (a) Fans
- (b) Unit air conditioners
- (c) Evaporative cooling: misting
- (d) Evaporative cooling: roof spray
- (e) Evaporative coolers
- (f) Indirect evaporative cooling

9.7 Heating-Only Systems
- (a) Wood heating devices
- (b) Electric resistance heaters
- (c) Gas-fired heaters
- (d) Ceiling electric resistance heat
- (e) Hot water boilers
- (f) Hot water baseboard and radiator systems
- (g) Radiant panels
- (h) Hydronic heating sizing
- (i) Hydronic zoning
- (j) Heating equipment efficiency, combustion, and fuel storage
- (k) Warm air heating systems

9.8 Heating/Cooling Systems
- (a) Cooling coils added to warm air furnaces
- (b) Hydronic and coils
- (c) Air-air heat pumps
- (d) Ground source heat pumps
- (e) Water source heat pumps

9.9 Psychrometrics and Refrigeration
References

Key Concepts

- passive system opportunities versus mechanical (active) system capabilities
- preliminary design phase (and associated HVAC system design process considerations)
- design development phase (and associated HVAC system design process considerations)
- design finalizing (construction documents and associated HVAC design efforts)
- central (as a means of organizing/categorizing HVAC systems)
- local (as a means of organizing/categorizing HVAC systems)
- heating system (to increase temperature)
- cooling system (to reduce temperature and relative humidity)
- distribution tree (to distribute and deliver central conditioning)
- controls (for system operation)
- building management system (BMS, a computerized/automated control system)
- automation (as a type of building system)
- neural networks (a control system that can learn)
- refrigeration (as a process and equipment cycle for cooling)
- compressive refrigeration (process and cycle)
- absorption refrigeration (process and cycle)
- evaporative cooling (misting, roof spray)
- indirect evaporative cooling (sensible evaporative refrigeration)
- electric resistance (as an energy conversion process)
- efficiency (as a performance measure)
- hydronic (as a system type)
- zoning (as a design analysis tool)
- psychrometrics (as a thermal analysis tool)

Chapter 10: Large Building HVAC Systems

Summary: This chapter addresses HVAC systems for large buildings and is complementary to Chapter 9 (which focuses on small-building HVAC systems). Considerations (such as IAQ) dealt with in previous chapters are referenced as an introduction.

Relationships between HVAC system selection and general building organization are considered in some detail. These basic coordination issues include: HVAC system zoning, matching thermal zones to system capabilities, whether a local or central system is appropriate, design intent relative to uniformity or diversity of the thermal environments within a building, space needs and availability for distribution trees, appropriate location(s) for central equipment components, whether the HVAC system should be concealed or exposed, and whether the HVAC system should be integrated with or kept separate from the building structural system. Options for distribution tree placement are illustrated and reviewed.

Four main classifications of HVAC systems are identified: direct refrigerant systems, all-air systems, air and water systems, and all-water systems. Each of these classifications holds many specific types and arrangements of systems. Direct refrigerant systems generally eliminate the need for a distribution tree but are typically used in smaller buildings; they were discussed in Chapter 9. All-air systems employ only air to provide heat transfer between the central station location and the conditioned spaces. Types of all-air systems include: single zone, multizone, single-duct variable air volume (VAV), fan-powered VAV, single duct with reheat, and double-duct systems. All-air systems require large distribution trees, but are a good choice from a comfort and indoor air quality perspective.

Air and water systems circulate both of these media from central station to conditioned spaces. Most of the heating/cooling is done via the water distribution tree. The air supply is generally provided to assist in maintaining indoor air quality. Air and water system types include (among other options): induction, fan coil with supplementary air, and radiant panel with supplementary air. Water loop heat pumps are included under this classification, but it is noted that they are often considered an all-water system. All-water HVAC systems require only a small distribution tree between central plant and conditioned spaces. Resolution of air quality issues with such systems is described as ambiguous.

Options for equipment placement and space requirements for heating/cooling and air-handling equipment are discussed. Guidelines are given for preliminary sizing of equipment rooms. The individual equipment items that comprise the central equipment for an HVAC system are discussed in turn. Such equipment includes: boilers of various types, chillers (compressive and absorption), condensing water equipment (cooling towers), energy conservation and energy storage equipment, air-handling equipment (including various fan types), and controls. Typical equipment is illustrated, several sample equipment layouts are given, and space requirements summarized.

Elements of air distribution systems are reviewed. Elements addressed specifically include: ducts, ceiling air supply, air supply for underfloor air distribution, and workstation delivery systems. Duct sizing estimates are discussed. Alternatives to conventional air supply/return are presented (for example, the air-extract window, air curtain window, and climate window).

Each of the named system types (VAV, induction, etc.) introduced at the beginning of the chapter is considered in greater detail. System characteristics are reviewed and typical applications discussed. Example buildings are employed to illustrate actual installations for some of the systems. Delivery and auxiliary equipment specific to certain systems is described and illustrated.

District heating and cooling is introduced. Cogeneration is defined; cogeneration history and applications are presented. Fuel cell applications for buildings are considered.

Chapter Outline

10.1 HVAC and Building Organization
- (a) Zoning
- (b) System anatomy
- (c) Central versus local systems
- (d) Uniformity versus diversity
- (e) Comparing systems and zones
- (f) Distribution trees
- (g) Central equipment location
- (h) Concealment and exposure
- (i) Mechanical-structural integration or separation
- (j) Distribution tree placement options

10.2 HVAC System Types
- (a) Direct refrigerant systems
- (b) All-air systems
- (c) Air and water systems
- (d) All-water systems
- (e) Equipment space allocations

10.3 Central Equipment
- (a) Boilers
- (b) Chillers
- (c) Condensing water equipment
- (d) Energy conservation equipment
- (e) GeoExchange systems
- (f) Energy storage
- (g) Air handling equipment
- (h) Controls

10.4 Air Distribution within Spaces
- (a) Air ducts
- (b) Ceiling air supply
- (c) Underfloor supply with displacement ventilation
- (d) Workstation delivery systems
- (e) Alternative supply/return systems

10.5 All-Air HVAC Systems
- (a) Single-zone systems
- (b) Single-duct VAV systems
- (c) Fan-powered VAV systems
- (d) Multizone systems
- (e) Single duct with reheat
- (f) Double-duct systems

10.6 Air and Water Systems
- (a) Induction
- (b) Fan-coil with supplementary air
- (c) Radiant panels with supplementary air
- (d) Water loop heat pump

10.7 All-Water Systems

10.8 District Heating and Cooling
- (a) High-temperature water and chilled water

10.9 Cogeneration
- (a) Electrical power generation at the site
- (b) Early on-site power generation
- (c) How cogeneration developed
- (d) Turbines and reciprocating engines
- (e) Cogeneration for housing
- (f) Fuel cells

References

Key Concepts

- zoning (as a design tool)
- central (as a system type)
- local (as a system type)
- diversity versus uniformity (in the interior environment)
- distribution trees (as an organizing concept and potential design tool)
- central HVAC systems
    - all-air (a system category)
    - air and water (a system category)
    - all-water (a system category)
- equipment location (as a design issue and determinant)
- concealment versus exposure (as a design approach/philosophy)
- systems integration or separation (as a design approach/philosophy)
- direct refrigerant system (DX; as a system type)
- constant volume (as an air distribution system type)
- variable volume (as an air distribution system type)
- supplementary air (related to water-based heating/cooling)
- heat pump (as an equipment/system type)
- boiler (central equipment)
- combustion air (as required for fuel-fired devices)
- chiller (central equipment)
- cooling tower (central equipment)
- energy conservation equipment (as a means of improving system efficiency)
- energy storage systems (as a means of improving system efficiency)
- air-handling equipment (central equipment)
- fan (for air circulation)
- controls (as a critical system element)
- distribution elements (ducts, pipes; as defining the distribution tree)
- underfloor air distribution (an alternative supply/return arrangement)
- workstation delivery system (as an alternative HVAC supply approach)
- district heating and cooling (as a system type)
- cogeneration (as an alternative to conventional energy supplies)

Chapter 11: Lighting Fundamentals

Summary: This is the first of six chapters that address building lighting systems. The focus of this chapter is the fundamentals of lighting; as such it introduces many concepts and much terminology that is probably new to most students. The concepts are critical to an understanding of lighting and the terminology is the key to clear communication of design intentions. This chapter provides a foundation for the design of lighting systems.

Lighting design is described as an art and a science that (for successful conclusions) requires a balance between quantitative and qualitative issues. Light is defined as a form of radiant energy ("visually evaluated radiant energy) with wavelength and frequency. The visible spectrum consists of all wavelengths that can be detected by the human eye; any limited cross-section of the spectrum is typically viewed as colored light, light distributed fairly equally across the spectral wavelengths is viewed as white light. Light striking a material can be transmitted, reflected, or absorbed. Transmission and reflection can be diffuse or non-diffuse (specular).

A number of lighting metrics are defined and explained: luminous intensity, luminous flux, illuminance, luminance, exitance, luminous efficiency (efficacy). Brightness is discussed relative to luminance. Equipment and methods for measuring illuminance, luminance, and reflectance are presented. Candela measurements and candlepower distribution curves for light sources are discussed. The inverse square law is reviewed.

The human eye and its function are discussed. Important elements of the eye (cornea, pupil, iris, lens, retina, fovea, optic nerve) are outlined. The respective roles that rods and cones play in vision are considered. Visual fields are introduced. Factors that affect visual acuity (the ability to distinguish detail) are presented and discussed in detail, and their interplay addressed. These factors are identified as primary (object size, luminance, contrast, and exposure time) and secondary factors. Lighting conditions that affect visual acuity are also identified as primary (illuminance and glare) and secondary factors. The nature of the observer's eye also plays a role in acuity. Discussion of these factors introduces issues such as photopic/scotopic vision, contrast as a metric, adaptation, and adaptation levels. The role of the "aging eye in lighting design is addressed.

The quantity aspect of lighting design is considered via discussion of illuminance, illuminance categories, and illuminance standards. It is noted that the question "How much light should I provide ... is not a simple one to answer. A discussion and comparison of British and North American illuminance recommendations is presented. Sample data tables and review of their use illustrate this discussion. Revised IESNA illuminance categories are introduced.

The quality aspect of lighting focuses upon glare. Glare is defined and categorized as direct glare (often as discomfort) and reflected glare (often as veiling reflections); disabling glare is also mentioned. The nature of these glare types is considered, along with their effects on occupants. Means of addressing direct glare in lighting design are presented, including numerical approaches such as visual comfort probability estimates and graphic approaches. Likewise, means of addressing reflected glare are considered, including contrast reduction, equivalent spherical illumination, and relative visual performance. Design approaches that can be used to control reflected glare are presented. Luminance ratio guidelines are presented. Occupant reactions to luminance patterns and lighting are explored.

Basic concepts and specifications that are employed to deal with the color of light are presented. These include color temperature and correlated color temperature for illuminant color, and color classification systems for object color. Common terminologies for object color are presented. Reactions to color are briefly explored.

Chapter Outline

11.1 Introductory Remarks

PHYSICS OF LIGHT
11.2 Light as Radiant Energy
11.3 Transmittance and Reflectance
11.4 Terminology and Definitions
11.5 Luminous Intensity
11.6 Luminous Flux
11.7 Illuminance
11.8 Luminance, Exitance, and Brightness
11.9 Illuminance Measurement
11.10 Luminance Measurement
11.11 Reflectance Measurements
11.12 Inverse Square Law
11.13 Luminous Intensity: Candela Measurements
11.14 Intensity Distribution Curves

LIGHT AND SIGHT
11.15 The Eye
11.16 Factors in Visual Acuity
11.17 Size of Visual Object
11.18 Subjective Brightness
11.19 Contrast and Adaptation
11.20 Exposure Time
11.21 Secondary Task-Related Factors
11.22 Observer-Related Visibility Factors
11.23 The Aging Eye
(a) Cornea
(b) Lens
(c) Pupil

QUANTITY OF LIGHT
11.24 Illuminance Levels
11.25 Illuminance Category
11.26 Illuminance Recommendations
(a) British lighting standards
(b) North American illuminance recommendations (IESNA)
(c) Evolution of IESNA illuminance recommendations

QUALITY OF LIGHTING
11.27 Considerations of Lighting Quality
11.28 Direct (Discomfort) Glare
11.29 Veiling Reflections and Reflected Glare
(a) Nature of the problem
(b) Contrast reduction
11.30 Equivalent Spherical Illumination and Relative Visual Performance
(a) Equivalent spherical illumination
(b) Relative visual performance
11.31 Control of Reflected Glare
(a) Physical arrangement of system elements
(b) Control of area brightness and eye adaptation level
(c) Control of source characteristics
(d) Changing the task quality
11.32 Luminance Ratios
11.33 Patterns of Luminance: Subjective Reactions to Lighting

FUNDAMENTALS OF COLOR
11.34 Color Temperature
11.35 Object Color
11.36 Reactions to Color
11.37 Chromaticity
11.38 Spectral Distribution of Light Sources
11.39 Color Rendering Index
References

Key Concepts

- Illuminating Engineering Society of North America (IESNA—a key source of lighting information and standards)
- science and art (describing the dual nature of architectural lighting)
- quantitative and qualitative (as two means of analysis and evaluation)
- light (as a physical phenomenon)
- wavelength (as a boundary for and fundamental property of light)
- transmittance, reflectance, and absorptance (interactions between light and materials)
- luminous intensity and flux (as critical light-source concepts)
- luminous efficacy (as the non-linear "conversion between power and light)
- illuminance (as a major lighting metric, objective, and criterion)
- brightness and luminance (as related, but different, lighting concepts)
- inverse square law (as a principle of light distribution)
- candlepower distribution curve (CDC, as a key descriptor of a light source)
- elements of the eye (as a basic lighting foundation)
- near, far, and peripheral vision areas (as they affect lighting design)
- visual acuity (as a driving force behind illuminance standards)
- contrast (as a fundamental visual issue)
- illuminance category (as a design criterion)
- glare (as a typical lighting quality problem)
- equivalent spherical illumination (ESI, as one metric of visual quality)
- luminance ratios (as a design criterion and analysis metric)
- video display terminal (as a substantial influence on lighting design)
- color metrics (as a vocabulary for dealing with color)
- color processes (as a means of "forming colors)
- spectral distribution (as a means of conveying "color" information)

Chapter 12: Light Sources

Summary: This chapter considers characteristics and typical applications of all commonly encountered light sources used in buildings. Daylight and electric light sources are included. The authors note that lighting accounts for a substantial portion of electricity use in non-residential buildings and that attempts to reduce such consumption will need to address daylighting and the efficacy of electric sources.

The nature of daylight as a light source for buildings is discussed. Factors affecting daylight availability are considered. Four basic sky conditions (fully overcast, clear—with and without sun, and partly cloudy) are presented and reviewed. The nature of these sky types as light sources is addressed along with a comparison of their differences. Sample data to quantify daylight source potential are provided.

Electric light sources (lamps) are presented in detail. Major lamp families (incandescent and electric discharge) are identified and commonly used lamps within each of these families are described and their characteristics reviewed. For each lamp type, information is provided on principles of operation, physical characteristics, and operating performance. Advantages and disadvantages of each lamp type with respect to efficacy, illuminant quality, installation, and control capabilities are considered. Generic performance data are provided for each lamp type.

Incandescent lamps include conventional filament lamps (in a wide range of options) and tungsten-halogen lamps. Electric discharge lamps include fluorescent (preheat, rapid-start, instant-start, compact, and special), mercury vapor, metal halide, and high-pressure and low-pressure sodium. Ballast types, characteristics, ratings, and applications are discussed, with emphasis on basic functions and ballast control capabilities. Each lamp type is addressed in detail, including development, typical uses, cautions, and appropriateness to common functions. Emerging inductance, light emitting diode, and sulfur lamp technologies are presented. Fiber optics is briefly touched upon.

Chapter Outline

Key Concepts

- luminous efficacy (as a measure of the efficiency of a light source)
- daylighting (as a design method and an intent)
- the nature of outdoor illumination (as a means of understanding this as a light source)
- design sky conditions (as a design resource and system component)
- electric lamp (as a class of light sources and system component)
- incandescent lamp (as a common electric lamp type)
- electric discharge lamp (as a family of common lamp types)
- ballast (as an operational and control device)
- life-cycle cost analysis (as a decision-making tool)

Chapter 13: Lighting Design Process

Summary: This chapter presents a recommended process for the design of lighting systems. Although generally suffused with examples from the realm of electric lighting, many of the concepts and issues are equally applicable to daylighting and daylighting-electric lighting systems. Evaluation of proposed solutions against applicable design intent and criteria—especially energy and cost criteria—is emphasized.

Lighting design is characterized as a combination of applied art and applied science. The chapter notes that there is no one “single” correct design solution to a lighting problem, but suggests that the analytically-focused process outlined in the chapter will lead to appropriate solutions. The goal of the lighting design process is said to be the creation of an efficient and pleasing interior. Four operative principles for lighting designs are presented. A more intuitive brightness design approach is mentioned by way of comparison.

The lighting design process is outlined as follows: identify project constraints, complete a task analysis, work through the design stage (the heart of the process), and evaluate the intended solution. Each of these elements of the process is examined in turn and in detail. Monetary and energy budgets impose external constraints on the design process that must be considered to reach a successful conclusion. Guidelines to consider when addressing each of these areas are provided. Elements of task analysis are reviewed: visual difficulty, time factor, nature of the occupant, the cost of visual errors, and special requirements related to the tasks. Rules-of-thumb for horizontal-to-vertical illuminance ratios for common lighting systems are given to assist in task analysis.

The discussion of preliminary design activities begins with a detailed discussion of energy considerations. Energy efficiency requirements and recommendations from ASHRAE/IES Standard 90.1 and other applicable guidelines are placed in context. During preliminary design, the quality or character of the lighting system is established. This involves the “feel” of the system. Options for illumination method (general lighting, local/supplementary lighting, and combined general and local lighting) are described. Within these methods, options for lighting systems (indirect, semi-indirect, direct-indirect, general diffuse, semi-direct, and direct) are described and illustrated. Characteristics, generic hardware types, and advantages/disadvantages of each system are presented--with an emphasis on the qualitative aspects of such systems. Effects of luminaire position, size, brightness, and patterning are considered. Some general user perceptions regarding space and lighting are explored.

Chapter Outline

13.1 General
13.2 Goals of a Lighting Design
13.3 Lighting Design Procedure
- (a) Project constraints
- (b) Task analysis
- (c) Design stage
- (d) Evaluation stage

13.4 Cost Factors
13.5 Power Budgets
13.6 Task Analysis
- (a) Difficulty
- (b) Time factor
- (c) Occupant
- (d) Cost of errors
- (e) Special requirements

13.7 Energy Considerations
13.8 Preliminary Design

13.9 Illumination Methods
- (a) General lighting
- (b) Local/supplementary lighting
- (c) Combined general and local lighting

13.10 Types of Lighting Systems
13.11 Indirect Lighting
13.12 Semi-Indirect Lighting
13.13 Direct-Indirect and General Diffuse Lighting
13.14 Semi-Direct Lighting
13.15 Direct Lighting
13.16 Size and Pattern of Luminaires
13.17 Other Design Considerations
References

Key Concepts

- systems design approach (design of building systems in an integrated fashion)
- project lighting cost framework (as an external design factor)
- project energy budget (as an external design factor)
- energy efficiency (as a pervasive design influence)
- ratio of horizontal to vertical illumination (as a design guideline)
- illumination methods (options for general approaches to providing light to a space)
- lighting system (options for luminaire-space relationships)
- luminaire placement (as an element of a design solution)

Chapter 14: Daylighting Design

Summary: Daylighting is described as an art and a science and is promoted as an important design intent and a valuable design tool—a means to improve both building and occupant performance. Daylighting design for Audubon House is presented as a summarizing case study.

The design of daylighting is an opportunity that needs to be grasped early in the design process and be refined throughout design. Building orientation and form must be addressed very early on. Daylighting can provide energy savings, views for occupants, and increased productivity. To do so successfully, however, glare and overheating must be controlled. Toplighting and sidelighting (unilateral and bilateral) are commonly used approaches to the delivery of daylight. Light pipes, light tubes, and heliostats are more specialized approaches.

Daylight factor is introduced as both a design criterion and a measure of daylighting performance. The daylight falling on a given point in a building is a mixture of a sky component, an externally reflected component, and an internally reflected component. Target daylight factors are often a key criterion in lighting system design—recommended values are suggested.

Several methods of daylight design and analysis are presented and illustrated by example. The distinction between design tool and analysis tool is emphasized. Several preliminary design tools are discussed: the 2.5H guideline, the 15/30 guideline, and sidelighting and toplighting guidelines. The analysis methods presented include: the CIE Method, the Graphic Daylighting Design Method, the IESNA Lumen Method, computer simulation programs, and physical modeling. Characteristics of the methods are noted, calculation procedures are outlined, and typical results shown. Comparisons of the methods are made along with comments on appropriate utilization of the tools.

Throughout the chapter architectural design issues that affect daylighting are highlighted. These include the importance of horizontal and vertical building surfaces and their reflectances, window details, glare and solar radiation control devices (sunshading), and lightshelves. Plans and sections illustrating these issues are provided.

Chapter Outline

14.1 The Daylighting Opportunity
- (a) Importance of daylighting design
- (b) Planning for daylight throughout design
- (c) Energy savings with daylighting
- (d) Goals of daylighting

14.2 Human Factors in Daylighting Design
- (a) Windows and view
- (b) Productivity and satisfaction
- (c) Controlling daylight in interior spaces
- (d) Minimize glare

14.3 Site Strategies for Daylighting Buildings
14.4 Aperture Strategies: Sidelighting
14.5 Aperture Strategies: Toplighting
14.6 Specialized Daylighting Strategies
14.7 Daylight Factor
14.8 Components of Daylight
14.9 Guidelines for Preliminary Daylighting Design
- (a) The 2.5H guideline
- (b) The 15/30 guideline
- (c) The sidelighting and toplighting daylight factor guideline

14.10 Design Analysis Methods
- (a) CIE method

Key Concepts

- daylighting (as a design intent and as a method)
- benefits of daylighting (as reasons to use in design)
- glare and cooling load (as potential drawbacks to poorly-done daylighting)
- aperture strategies (as a means of implementation)
- unconventional aperture strategies (as alternative means of implementation)
- daylight factor (as a design criterion and performance measure)
- daylight factor components (as a means of understanding the daylight resource)
- design guidelines (as tools for preliminary design efforts)
- design analysis methods (as tools for design refinement)
- computer simulations (as often-encountered analysis tools)
- physical modeling of daylighting (as a useful design and analysis tool)

Chapter 15: Electrical Lighting Design

Summary: This chapter addresses three closely related (but also distinct) aspects of electric lighting design: luminaires (lighting fixtures), lighting controls, and calculations for the analysis of electric lighting systems.

Lighting system design considerations related to luminaires are addressed in detail. The purpose of a luminaire is twofold: to hold, protect, and connect a lamp(s) to the electrical system; and to photometrically control the light output. The need for trade-offs and qualitative decisions when selecting luminaires for a particular space is emphasized. Light distribution characteristics of a luminaire are explored via interpretation of typical luminaire distribution curves. Issues to consider include: uniformity of distribution and resulting illumination, efficiency, diffuseness, control of potential direct and reflected glare components, lamp shielding, and ceiling illumination potential. The light control functions of a luminaire are explored through discussion of lamp shielding, reflector patterns and materials, and diffuser types and materials. Retrofit reflectors for existing luminaires are looked at with some skepticism.

Fundamentals of luminaire location are discussed. For uniform illuminance, meeting spacing criteria limits (spacing to mounting height ratio) is critical. Mounting height relative to the ceiling plane is an issue for luminaires with an upward light component. Guidelines for quality luminaire construction and installation are presented, including a review of common diffuser materials. In addition, guidelines are given for evaluation of proposed luminaire selections. Two metrics of luminaire performance are used: the coefficient of utilization, which expresses luminaire efficiency as installed in a given space; and luminaire efficacy rating, which expresses luminaire efficacy independent of its use in a space.

The primary purposes of lighting controls are given as flexibility and economy. Flexibility is generally addressed in terms of meeting design intent and facility usage; economy in terms of costs and energy use. Lighting control functions are identified as switching and dimming. These functions are achieved by control devices assembled into control systems. The lighting control system may be a part of a building automation or energy management system. Criteria for design of control systems are noted as energy conservation, cost reduction, and operating flexibility.

Switching is defined as an on-off function. ASHRAE/IESNA Standard 90.1 requires minimum lighting control capabilities and rewards automatic controls (as being more effective than manual). Control initiation is either manual or automatic (or a combination of these). Manual control is noted as giving employees a sense of satisfaction. Automatic control can be static (open circuit) or dynamic (with closed-loop feedback). Lighting control strategies presented include: system tuning, lumen maintenance, and daylighting compensation. Occupancy sensors and time-tracking controls are discussed.

Calculation of average uniform illuminance using the zonal cavity or lumen (flux) method is reviewed and illustrated by worked examples. The basis of the lumen method is explained and all relevant variables employed by the method are discussed. These include room, ceiling, and floor cavities; light-loss factors (recoverable and non-recoverable); surface reflectances; lamp lumens; and the coefficient of utilization (CU). The derivation or source of all these variables is discussed. An approximate method utilizing the zonal cavity approach is presented and compared to the full-blown method. Luminaire layout that would follow completion of the calculations is explored. Other analysis methods, including modular lighting design tools, isolux charts, illuminance cone charts, pre-established tables, and computer simulations, are introduced. Examples of output from a typical computer program are shown. Use of the inverse square law to determine illuminance from a point source is illustrated. Illuminance from line and area sources is briefly considered. Zonal cavity calculations for luminance are presented and illustrated. Evaluation of proposed solutions against lighting, energy, and cost criteria is emphasized.

Chapter Outline

15.26 Calculating Illuminance at a Point
15.27 Design Aides
    (a) Isolux charts
    (b) Illuminance cone charts
    (c) Illuminance tables and charts
15.28 Calculating Illuminance from a Point Source
15.29 Calculating Illuminance from Linear and Area Sources
15.30 Computer-Aided Design
15.31 Computer-Aided Design: Illustrative Example
15.32 Average Luminance Calculations

EVALUATION
15.33 Design Evaluation
References

Key Concepts

- luminaire characteristics and properties (as elements of a design solution)
- lighting control purposes (as a match for lighting design intents)
- lighting control criteria (as benchmarks for proposed control schemes)
- code requirements for controls (as an external design influence)
- dimming and switching (as basic control functions)
- system tuning (as a follow-through to off-site design)
- lumen maintenance (as a lighting control strategy)
- daylight compensation (as a lighting control strategy)
- zonal cavity calculation method (as a manual analysis method)
- point-source calculation method (as a manual analysis method)
- line-source and area-source calculation methods (as available analysis methods)
- computer simulations (as a computerized design and analysis tool)

Chapter 16: Electric Lighting Applications

Summary: This chapter presents information on two broad topical areas: an overview of guidelines and considerations for lighting of various building types and occupancies and a review of remote-source lighting systems. The lighting application guidelines comprise the majority of the chapter.

It is not possible to truly summarize the information presented on lighting applications for various building types and occupancies. For each application, however, guidelines are provided to assist with developing a general approach, selecting sources and fixtures, undertaking design implementation, and selecting appropriate controls. A detailed discussion of lighting for areas with VDTs is presented. Task-ambient lighting systems are also considered. Options for emergency lighting (central and distributed) and exit signs (several types) are reviewed. Numerous photos and diagrams are used to illustrate the various lighting applications.

Remote-source lighting systems are outlined and appropriate applications suggested. Such systems include fiber optic (FO) lighting, hollow and prismatic light guides, and prismatic film light guides. The terminology of fiber optic lighting is reviewed.

Chapter Outline

16.19 Lighting for Areas with Visual Display Terminals
- (a) Equipment
- (b) Location
- (c) Luminance ratios
- (d) Light delivery
- (e) Finishes

16.20 Office Lighting Guidelines
- (a) Private offices
- (b) General offices
- (c) Office lighting equipment
- (d) Maintenance
- (e) Fenestration
- (f) Control

16.21 Task-Ambient Office Lighting Design Using Ceiling-Mounted Units
16.22 Task-Ambient Office Lighting Using Furniture-Integrated Luminaires
16.23 Integrated and Modular Ceilings
16.24 Lighting and Air Conditioning

INDUSTRIAL LIGHTING
16.25 General Information
16.26 Levels and Sources
16.27 Industrial Luminance Ratios
16.28 Industrial Lighting Glare
16.29 Industrial Lighting Equipment
16.30 Vertical-Surface Illumination

SPECIAL LIGHTING APPLICATION TOPICS
16.31 Emergency Lighting
- (a) Codes and standards
- (b) Minimum illumination levels and duration of emergency lighting
- (c) Central battery emergency lighting systems
- (d) Distributed (local) emergency lighting arrangements
- (e) Emergency lighting design considerations
- (f) Exit lighting

16.32 Floodlighting
16.33 Street Lighting
16.34 Light Pollution
16.35 Remote Source Lighting
16.36 Fiber-Optic Lighting
16.37 Fiber-Optic Terminology
16.38 Fiber-Optic Lighting—Arrangements and Applications
- (a) Axial-mode linear devices
- (b) Axial-mode discrete sources
- (c) Lateral-mode fiber-optic lighting

16.39 Hollow Light Guides
16.40 Prismatic Light Guides
16.41 Prismatic Film Light Guide
16.42 Remote Source Standards and Nomenclature
References

Key Concepts

- the application of lighting principles to specific situations (as the essence of design)
- architectural lighting element (as a design option)
- visual display terminal (VDT, as a ubiquitous lighting design issue)
- specific occupancies (as having identifiable needs and opportunities for lighting)

- emergency lighting (as a life-safety issue)
- exit lighting (as a life-safety issue)
- remote-source lighting (as a rapidly developing area in lighting design)

Chapter 17: Fundamentals of Architectural Acoustics

Summary: This chapter provides an introduction to architectural acoustics. Numerous acoustical terms and concepts are introduced, defined, and explained. Sample calculations for several types of sound measurements are given.

Architectural acoustics is defined as the technology of designing spaces to meet hearing needs. Wanted sounds are distinguished from noise (unwanted sounds). Providing for good acoustics in modern buildings is noted as an increasingly difficult task. The common elements of all acoustic situations are identified: source, transmission path, and receiver. Sound is thought to be best described for purposes of building design as “an audible signal.”

Sound generation and propagation are discussed. The fundamental properties of frequency, wavelength, and speed of propagation are explored. Means of characterizing frequency patterns (pure tones, harmonics, pitch, octaves) are considered. Human hearing and the functioning of the ear are reviewed. The response patterns of the ear are explored. The concept of equal loudness contours is presented and the implications of this concept considered. Masking and directivity effects are discussed.

The characteristics of sound sources—primarily speech—are outlined. The numerous ways in which the magnitude of sound is described are reviewed in detail. These include sound intensity, sound pressure, and sound power—as well as the derivative expressions of sound intensity level, sound pressure level, and sound power level. The relationship between sound intensity and free-field propagation is defined and illustrated by sample calculations. It is noted that the human ear responds to sound magnitude logarithmically, not arithmetically. The concept of the decibel is thus introduced and then illustrated by example and calculations. The relationships between sound intensity, pressure, and power are defined. The use of an integrating sound level meter to measure sound pressure levels is discussed. Weighting network use, to match sound level meter response to human response, is explained.

The effects of noise and of annoyance with sound are considered. Indicators of these effects, such as articulation index and speech interference level, are explained. Annoyance patterns (general patterns of human response) are given. Several design criteria for noise are presented and explained. These include noise criterion (NC) curves, room criterion (RC) curves, noise rating (NR) curves, and balanced noise criterion (NCB) curves. Special mechanical noise considerations are noted and hearing protection issues introduced. Vibration is identified as being distinct from sound (noise).

Chapter Outline

17.1 Architectural Acoustics
17.2 Sound
- (a) Speed of sound
- (b) Wavelength
- (c) Frequency
- (d) Octave bands
- (e) The concept of sound magnitude
- (f) Sound propagation

17.3 Hearing
- (a) The ear
- (b) Equal loudness contours
- (c) Masking
- (d) Directivity
- (e) Discrimination

17.4 Sound Sources
- (a) Speech

(b) Other sounds
17.5 Expressing Sound Magnitude
(a) Sound power
(b) Sound pressure
(c) Sound intensity
(d) The decibel
(e) Sound power level
(f) Sound pressure level
(g) Measuring sound
17.6 Noise
(a) Annoyance
(b) Noise criteria
(c) Noise criteria curves
(d) Room criteria curves
(e) High noise levels and hearing protection
17.7 Vibration
References

Key Concepts

- architectural acoustics (as an important area of design)
- difficulty of providing good acoustics (as a reminder to properly consider this aspect of design)
- common elements of all acoustic systems (as a useful organizational structure)
- frequency (as a fundamental property of sound)
- speed of sound (as slower than light, critical to consider, and variable with material)
- descriptions of sound magnitude (as involving numerous measures and units)
- free-field sound propagation (as a design situation)
- basics of human hearing (as the foundation for architectural acoustics)
- equal loudness contours (as fundamental to understanding human response to sound)
- masking (as a design tool or as a problem)
- logarithmic response of human ear (explaining qualitative evaluations of sound)
- decibel scale (used universally to quantify sound magnitude)
- meaning of the term “level” (to signify a ratio, expressed as a decibel value)
- weighting (of sound measurement devices; available options)
- noise and annoyance (as undesirable acoustic situations)
- noise or room criterion curves (as a typical means of expressing design criteria)
- hearing protection versus comfort (as a design objective in some spaces)
- vibration (felt by occupants versus being heard)

Chapter 18: Sound in Enclosed Spaces

Summary: This chapter addresses the propagation and distribution of sound in enclosed spaces—a subject known as room acoustics. The primary acoustical design intent in most enclosed spaces is to maintain and enhance the intelligibility of audible information. Sound from a source may be absorbed, reflected, or transmitted as it interacts with room enclosure elements. The two primary acoustic characteristics of a space are its absorption and its reverberation.

Sound absorption plays an important role in room acoustics. Coefficient of absorption (which varies with frequency) is an indicator of a material's sound absorption characteristics. The total absorption of a given amount of material is proportional to its area and absorption coefficient—and is expressed in sabins (square feet or square meters). Acoustic (absorptive) materials come in a number of forms: fibrous materials, panel resonators, and volume (Helmholtz) resonators. Patterns of performance for absorptive materials are summarized. It is emphasized that the means of installation will affect the performance of acoustic materials; typical installation options are discussed and performance patterns summarized.

Room acoustics are discussed in terms of reverberation and sound fields. Reverberation is defined as the persistence of a sound after the sound source has ceased. Reverberation time is presented as a measure of reverberation. A means of estimating reverberation time is given. Reverberation is related to sensations of acoustical liveness or deadness. Articulation is noted as the converse of reverberation or reverberance.

Sound fields in an enclosed space are defined as the free (or far) field, the near field, and the reverberant field. The relationship between sound power level and sound pressure level in a space is established and defined mathematically. Directivity factor and room constant play a role in this relationship. Sample calculations are used to illustrate this relationship as a means of obtaining noise reduction via absorption. It is noted that a doubling of absorption only reduces noise level by 3 decibels (the law of diminishing returns). Noise reduction coefficient (NRC) is introduced and critiqued.

Reverberation criteria for speech spaces are discussed and an equation for calculating optimum reverberation time is given. The effects of echoes are discussed, including their effect on intelligibility and directivity. Criteria for music performance are also addressed. Numerous acoustic characteristics such as fullness, clarity, and brilliance are explained. Sound paths are discussed with respect to specular reflections, echoes, flutter, focusing, creep, and standing waves. Resonance is defined. Ray diagrams are introduced as a useful design tool. Auditoriums are presented as a particular room acoustics challenge—with guidelines and sample calculations. The components (input, amplifier, and loudspeakers) and objectives of sound reinforcing systems are introduced. Important characteristics of such systems are noted.

Chapter Outline

18.1 Sound in Enclosures

ABSORPTION
18.2 Sound Absorption
18.3 Mechanics of Absorption
18.4 Absorptive Materials
18.5 Installation of Absorptive Materials

ROOM ACOUSTICS
18.6 Reverberation
18.7 Sound Fields in an Enclosed Space
18.8 Sound Power Level and Sound Pressure Level

18.9 Noise Reduction by Absorption
18.10 Noise Reduction Coefficient

ROOM DESIGN
18.11 Reverberation Criteria for Speech Rooms
18.12 Criteria for Music Performance
18.13 Sound Paths
(a) Specular reflection
(b) Echoes
(c) Flutter
(d) Diffusion
(e) Focusing
(f) Creep
(g) Standing waves
18.14 Ray Diagrams
18.15 Auditorium Design

SOUND REINFORCEMENT SYSTEMS
18.16 Objectives and Criteria
18.17 Components and Specifications
(a) Input
(b) Amplifier and controls
(c) Loudspeakers
18.18 Loudspeaker Considerations
References

Key Concepts

- behavior of sound in enclosed space (as opposed to free field behavior)
- intelligibility (as a primary design intent)
- room acoustics (involving design for sound within a space)
- room characteristics (relative to absorptance and reverberation)
- sound absorption (and related characteristics and indicators)
- acoustic materials (types, properties, and performance)
- effectiveness of material installation details (as a design consideration)
- reverberation (as a key acoustic property and design criterion)
- articulation (as the converse of reverberation)
- sound fields in enclosed spaces (as a design concern)
- relationship between SPL and PWL (as controlled by design)
- law of diminishing returns (with respect to adding absorption)
- NRC (noise reduction coefficient, as a misnamed acoustic property)
- optimum or maximum reverberation time (as a design criterion)
- acoustic characteristics (numerous characterizations of sound quality)
- ray diagramming (as a design tool)
- auditorium design (as a particular concern of room acoustics)
- remedial treatment (for existing spaces)
- sound reinforcement system (as often required in larger spaces)

Chapter 19: Building Noise Control

Summary: This chapter addresses numerous aspects of noise control in buildings. Noise reduction in general involves three principles: reduction of noise generation at the source; reduction of noise transmission; reduction of noise at the receiver. Design for speech privacy involves the above factors plus the use of masking noise if appropriate. Noise reduction involves the conversion of sound to heat via absorption.

Absorptive room treatment will reduce the reverberant sound level within a space but have little effect on adjacent spaces. Numerous types of absorbent materials are available. These include panel resonators, cavity resonators, acoustic tiles, perforated metal-faced units, acoustic panels, acoustic plaster, sound blocks, wall panels, resonator sound absorbers, and carpeting and drapery. Characteristics and applications of these materials (and elements) are given, with recommendations for the use of absorption techniques. Acoustically transparent materials are defined.

Sound isolation involves the reduction of sound transmission between enclosed spaces. Airborne sound and structure-borne sound are noted as involving differing origins. Airborne sound is generally less disturbing than structure-borne sound. Transmission loss (TL) and noise reduction are introduced as indicators of the performance of a barrier to airborne sound. Transmission loss (TL) is defined as the ratio of acoustic energy re-radiated by a barrier to that incident on the barrier. Noise reduction (NR) is defined as the difference in sound intensity levels between two adjoining rooms. The relationship between TL and NR is described and related to design factors.

The mass law is introduced as defining the relationship between transmission loss and frequency and also surface mass; a doubling of either mass or frequency will lead to a theoretical increase of 6 dB in TL. Actual performance in the field is typically only 4 dB per octave. Stiffness and resonance are noted as influencing barrier transmission loss. Resonance dips are described, and critical frequency discussed. The performance of compound barriers (cavity walls) is explored.

The concept and application of sound transmission class (STC) are presented. Sound transmission class contours are introduced. The effects of composite barrier construction and leaks in barriers are described and illustrated by example. STC ratings for typical constructions are given. The effects of doors and windows on barrier ratings are discussed. Diffraction at barriers is considered. Flanking is defined and illustrated.

Speech privacy design concerns in both enclosed and open office type settings are reviewed. Sound isolation descriptors are introduced, along with the concept of masking sounds. Factors affecting speech privacy in enclosed space situations are presented. Levels of speech privacy are defined. Design guidelines are considered. Speech privacy considerations in open area offices are emphasized as being substantially different from those in enclosed spaces. A detailed discussion of open work area design is given—with recommendations. Articulation index is discussed.

Articulation class is introduced. Masking sound and masking sound systems are discussed. Components of a masking system are outlined. A number of standards addressing open work area speech privacy are noted.

The importance of designing to control structure-borne sound is emphasized. Methods for controlling impact noise are reviewed. Impact isolation class (IIC) is a single-number rating for floor constructions. Noise control for mechanical and electrical system equipment and components is addressed. Vibration reduction techniques (inertia blocks, resilient support, and floating floors) are described. Control of duct system noise is important. Active noise cancellation is an alternative noise reduction technique for non-random noises. Elements of such a system are described. The concept of a sound isolation enclosure is presented.

Recommendations for STC and IIC criteria are given for multi-family occupancies and several other buildings types. Noise control issues are summarized for schools (auditoriums, classrooms, music suites, dining areas, gymnasiums, swimming pools, and shops), offices, and apartment buildings. Sound propagation outdoors is reviewed.

Reference materials at the end of the chapter include a glossary, a listing of reference standards, a table of units and conversions, a description of symbols and abbreviations, and chapter references.

Chapter Outline

(i) Standards

STRUCTURE-BORNE NOISE
19.22 Structure-Borne Impact Noise
19.23 Control of Impact Noise
(a) Cushion the impact
(b) Float the floor
(c) Suspend the ceiling—and use an absorber in the cavity
(d) Isolate all piping
19.24 Impact Isolation Class

MECHANICAL SYSTEM NOISE CONTROL
19.25 Mechanical Noise Sources
19.26 Quieting of Machines
19.27 Duct System Noise Reduction
19.28 Active Noise Cancellation
19.29 Piping System Noise Reduction
19.30 Electrical Equipment Noise
19.31 Noise Problems Due to Equipment Location
19.32 Sound Isolation Enclosures, Barriers, and Damping

STC AND IIC RECOMMENDATIONS AND CRITERIA
19.33 Multiple-Occupancy Residential STC/IIC Criteria
19.34 Specific Occupancies
(a) Schools
(b) Houses of worship
(c) Offices
(d) Apartment buildings

OUTDOOR ACOUSTIC CONSIDERATIONS
19.35 Sound Power and Pressure Levels in Free Space (Outdoors)
19.36 Building Siting

REFERENCE MATERIAL
19.37 Glossary
19.38 Reference Standards
19.39 Units and Conversions
19.40 Symbols
References

Key Concepts

- principles of noise reduction (as the fundamental basis for such design efforts)
- absorption (its capabilities and types of materials)
- acoustically transparent (as a material type and useful concept)
- airborne and structure-borne sound (as distinct design issues)
- sound isolation (as a design strategy)
- transmission loss and noise reduction (as barrier performance measures)
- mass law (as the basis for transmission loss performance)
- sound barrier properties (as they affect barrier performance)
- sound transmission class (as a single number indicator of barrier performance)
- composite barriers (composed of more than one construction type in parallel)
- leaks (as a fatal flaw in a sound barrier)
- diffraction at barriers (as an issue for design consideration)
- flanking (as a weak link in barrier performance; path of least resistance)
- speech privacy (as a design intent)

- degrees of privacy (as a design criterion)
- enclosed space versus open plan office acoustics (as distinct issues)
- sound isolation (as a design intent or method)
- articulation index (as an indicator of acoustical performance)
- masking noise system (as a design tool)
- airborne, structure-borne, impact noise (as specific design concerns)
- impact isolation class (IIC; as a performance indicator for impact isolation)
- noise control for mechanical/electrical equipment (as a critical design concern)
- active noise cancellation (as a technology and a design tool)
- pre-planning (to avoid acoustic problems through selective location of spaces and equipment)
- building siting (as an acoustic design tool)

Chapter 20: Water and Basic Design

Summary: This chapter begins with the quote: "The next great world crisis will be water supply." This sets the stage for a review of the many roles water plays in our buildings—under the context of increasing population and water usage. Historically, designers have had to deal with keeping water out of buildings; more recently they have also had to deal with making it available within buildings. Water can provide nourishment, be used for general cleaning and personal hygiene, play a ceremonial role, be used to remove wastes, assist in the cooling of buildings and people, be used ornamentally, and extinguish fires. Water also is used extensively in the construction of buildings and manufacture of building materials.

The hydrologic cycle describes the continuous process of evaporation, rainfall, runoff, and evaporation that replenishes the world's supply of fresh water. Precipitation is a resource (like solar energy, and climate-dependent) that is generally extensive but diffuse. Runoff can concentrate rainfall and make it more readily available for human use (although less pristine). Rainwater that penetrates the soil is known as soil moisture, when it reaches a level where the soil is saturated it becomes groundwater. The upper surface of the groundwater layer is called the water table.

Planning for water usage involves matching needs with resources. The extent of needs can vary greatly with philosophy of use—ranging from conventional practice usage patterns to less demanding conservation practices. Preliminary estimates of water supply requirements can be made on a per capita basis. Plumbing codes specify fixture requirements for different building types; these are always minimum acceptable requirements. Water can be supplied by public systems (distribution mains) or private systems (wells). Rainwater collection may be used as a water source. Cistern sizes and rainwater capabilities can be estimated for preliminary design purposes.

Sewage may be handled either by private systems (septic tanks, etc.) or by public systems (collection mains). Sewage flow rates can be estimated on a per capita basis for different occupancy types. Private sewage disposal methods include septic tanks and drainfields, leaching mounds, and sewage lagoons—all of which must be properly considered very early in the design process.

Rainwater and its control can influence site design and building design. Gutters, downspouts, and leaders may be provided to direct rainfall from roof areas. Historically, rainwater was quickly directed off site. There is a trend, however, for communities to ask or require that runoff problems be solved on site rather than downstream. Retention of rainwater on roofs for later discharge to the site is one such approach. The use of pervious surfaces on site, such as porous pavement materials, is another. Water recharge typically involves holding water on site long enough for it to percolate into the soil; this may involve trenches, dry wells, basins, or ponds. Site conservation of water resources may lead to the use of hydrozone or xeriscape landscaping practices.

Chapter Outline

20.1 Water in Architecture
- (a) Nourishment
- (b) Cleansing and hygiene
- (c) Ceremonial uses
- (d) Transportation uses
- (e) Cooling
- (f) Ornamental uses
- (g) Protective uses

20.2 The Hydrologic Cycle

20.3 Basic Planning
- (a) Water supply

(b) Cisterns
(c) Required facilities
(d) Sewage
20.4 Rainwater
20.5 Collection and Storage
20.6 Rainwater and Site Planning
(a) Roof retention
(b) Porous pavement
(c) Site design for recharging
20.7 Components
References

Key Concepts

- hydrologic cycle (as a driving force behind water resources)
- water characteristics (reflectivity, liquidity, life-sustaining)
- potable water (suitable for human consumption)
- sewage (sewer; liquid-borne waste)
- current and conservation practices (as they differentially affect water demands)
- plumbing fixture (as a user of water and supplier of wastes)
- cistern (for rainwater storage)
- catchment area (the collector size for rainfall resources)
- plumbing code (for minimum acceptable practices)
- septic tank (a means of private disposal of sewage)
- drainfield (an adjunct to the septic tank)
- groundwater recharge (as a philosophy for runoff control or good water management)
- roof retention (as a means of reducing runoff)
- hydrozone (as a landscape planning concept)
- xeriscape (as a landscaping approach)

Chapter 21: Water Supply

Summary: This extensive and diverse chapter addresses potable water supply systems for buildings—including issues of water quality, distribution, resource conservation, water heating (conventional and solar), and bathroom/fixture design. Site irrigation is also discussed. Sample calculations are provided for a number of typical design concerns.

Water quality is generally judged by assessment of its physical, chemical, biological, and radiological characteristics. Physical characteristics include turbidity, color, taste and odor, temperature, and foamability. Chemical characteristics include alkalinity and pH, hardness, and concentrations of toxic substances, chloride, metals, nitrates, pesticides, and sodium. Biological characteristics focus on disease-producing organisms (including E.coli bacteria). Radiological characteristics are likely to be of regional scale and concern.

Filtration is presented as a first step toward water treatment. A variety of filtration processes are covered, including sedimentation and flocculation as pre-filtering processes, slow sand filters, Diatomaceous Earth filters, direct filtration, membrane filtration, cartridge filtration, and other filters (activated carbon, ceramic, Pasteur). Typical applications and capabilities for each type of filter are covered.

Disinfection is noted as the most important health-related water treatment. Disinfection methods include: chlorination and chloramine, ozonation, nanofiltration, and ultraviolet radiation. Capabilities and applications for these disinfection processes are addressed. Other treatments (aeration or oxidation; corrosion control; softening using ion exchange, reverse osmosis, or electrodialysis; control of nuisance materials; fluoridation; and distillation) are also considered.

Wells as a source of potable water are discussed, with substantial detail given regarding the equipment and accessories necessary to operate a well-source system. Well types include driven, bored, jetted, and drilled. Pumps are necessary to the operation of virtually all wells. Pump types include positive displacement pumps (reciprocating and rotary), centrifugal pumps, turbine pumps, jet or ejector pumps—some available in submersible configurations. The process of selecting a pump and associated pressure tank is outlined.

Domestic (or service) hot water systems are examined at length. Water temperature and anticipated flow requirements are covered. Heat sources and equipment are presented and compared. Heating of water may be direct or indirect; delivery may be from tanks or from tankless heaters. The full range of energy sources discussed under space heating (in earlier chapters) may be used to heat domestic water. The "energy factor" (EF) was developed to rate the annual overall efficiency of water heaters. Central or distributed (local) water heating equipment is available. An example of sizing a conventional heater is given. The concept of distribution tree is used to describe hot water piping layouts. Hot water distribution may be "dead-ended" or recirculated. Flow may be by thermosiphon ("stack") effect or forced by a pump. Numerous control options exist—and are generally adopted for safety, performance enhancement, or energy conservation.

Solar water heating options are covered in detail and illustrated by sample calculations. Passive and active solar heating are both possible. Direct or indirect heating of water may be chosen depending upon solar system type. Batch, thermosiphon, closed-loop, freeze-resistant, drain-back, drain-down, air-to-liquid, and phase-change systems are discussed with respect to characteristics and typical applications. Swimming pool heating is identified as a viable use for solar water heaters. Heat pump water heaters are also considered.

A practical and philosophical discussion of plumbing fixtures and their impact on space planning and building occupants is presented. Lavatories, tubs/showers, toilets, urinals, and faucets are explored. Toilets (water closets) include conventional (washdown, siphon jet, siphon vortex, and blowout), watersaving, low-consumption, and waterless types. Flush valve and flush tank water sources are options. Issues relating to use of watersaving and low-consumption toilets are considered. Examples of water-conserving products are given. Accessibility and privacy concerns are examined.

Distribution of hot and cold water from source to fixtures is addressed with principles and examples. Upfeed, pumped upfeed, hydro-pneumatic, and downfeed distribution configurations are discussed in the context of typical applications. The concept of static pressure is presented. Equipment for water distribution systems is detailed and discussed—including piping, fittings, insulation, accessories, supports, tanks, and controls. The procedure for sizing of water pipes is presented and calculations illustrated. The chapter concludes with a brief look at on-site irrigation systems.

Chapter Outline

21.1 Water Quality
- (a) Physical characteristics
- (b) Chemical characteristics
- (c) Biological characteristics
- (d) Radiological characteristics

21.2 Filtration
- (a) Sedimentation
- (b) Coagulation
- (c) Flocculation
- (d) Slow sand filters
- (e) Diatomaceous Earth filters
- (f) Direct filtration
- (g) Membrane filtration
- (h) Cartridge filtration
- (i) Other filters

21.3 Disinfection
- (a) Chlorination
- (b) Chloramine
- (c) Ozonation
- (d) Ultraviolet radiation
- (e) Nanofiltration

21.4 Other Water Treatments
- (a) Aeration (oxidation)
- (b) Corrosion control
- (c) Softening
- (d) Nuisance control
- (e) Fluoridation
- (f) Distillation

21.5 Water Sources
- (a) Wells
- (b) Pumps
- (c) Pressure tanks

21.6 Hot Water Systems and Equipment
- (a) Water temperature
- (b) Heat sources and methods
- (c) Tankless water heaters
- (d) Energy factors
- (e) Central versus distributed equipment
- (f) Distribution trees
- (g) Variable storage temperature
- (h) Conventional water heater selection
- (i) Solar water heating

    (j) Heat pump water heaters
21.7 Fixtures and Water Conservation
    (a) Physiology, psychology, and fixtures
    (b) Lavatories
    (c) Whole-body cleansing
    (d) Elimination
    (e) Conventional toilets
    (f) Watersaver toilets
    (g) Low-consumption toilets
    (h) Flushing controls
    (i) Waterless toilets
    (j) Appliances
21.8 Fixture Accessibility and Privacy
    (a) Accessibility
    (b) Privacy
21.9 Water Distribution
    (a) Static pressure
    (b) Upfeed distribution
    (c) Principles of downfeed distribution
    (d) Tall building downfeed distribution
    (e) Pipe and tube expansion
    (f) Pumped upfeed distribution
21.10 Piping, Tubing, Fittings, and Controls
    (a) Piping, tubing, and fittings
    (b) Plastic pipe
    (c) Valves and controls
    (d) Pipe support
    (e) Shock and hot water expansion
    (f) Condensation or "sweating"
    (g) Heat conservation
21.11 Sizing of Water Pipes
21.12 Irrigation
References

Key Concepts

- potable water (as a benchmark or standard)
- water quality (as a measure of potability)
- high- and low-grade (as regards water needs/resources)
- physical characteristics (as a class of quality indicators)
- chemical characteristics (as a class of quality indicators)
- biological characteristics (as a class of quality indicators)
- radiological characteristics (as a class of quality indicators)
- filtration (as a quality-enhancing process)
- disinfection (as a quality-enhancing process)
- softening (as a quality-enhancing process)
- distillation (as a quality-enhancing process)
- wells (as a water source)
- water heater (as an equipment type)
- central versus distributed (local) equipment (as a design decision)
- distribution tree (as a design visualization tool)
- distribution system type (as a design decision)
- passive or active (water heating, as a design option)
- swimming pool heating (as a good match of need and resource)
- fixture (plumbing, as a design element and water user)
- conservation (as a design consideration)

- elimination (as a touchy design issue)
- accessibility (as a design issue)

Chapter 22: Liquid Waste

Summary: This chapter focuses upon the problem of removing water-borne wastes from buildings. Conventional DWV (drainage, waste, and vent) systems for removal and treatment of sanitary wastes are covered in detail, along with resource-conserving alternatives. Graywater options and stormwater removal and treatment are also covered.

Waterless alternatives to the toilet and urinal are presented. Such alternatives include composting toilets, vault-type toilets (for example the Clivus Multrum and Phoenix), heater-assisted composting toilets, and waterless urinals. The character, installation, and operation of these systems are described.

The principles of operation of conventional (water-based) sanitary drainage systems are reviewed. Key elements of DWV systems that define these principles are presented and discussed. These elements include traps, vents, air gaps, and vacuum breakers. The purpose of each of these elements is explained. Piping, fittings, and accessories for DWV systems are also discussed in detail. The range of piping materials found in drainage systems is reviewed and commonly encountered fittings and accessories described and explained.

The design process and calculation methods for residential waste piping systems are presented, with a worked-out example. The more complicated process of waste system design for larger buildings is then presented. Planning and rough-ins are considered, with examples. An alternative single-pipe sanitary drainage system (the Sovent system) is introduced.

On-site treatment of sewage for individual buildings is addressed in some detail. Primary, secondary, and tertiary treatments are explained and devices and processes for achieving these treatment levels are covered. Typical components of on-site treatment include septic tanks, aerobic treatment units (ATUs), seepage pits (cesspools), disposal fields (drainfields), mounds with leaching beds, and buried sand filters. A sizing example for a septic tank/drainfield is given.

Options for on-site sewage treatment for multiple building situations are also presented. These include open sand filters, recirculating sand filters, lagoons (anaerobic, aerobic, aerated, and faculative), constructed wetlands, greenhouse ecosystems, and the Pasveer oxidation stream process. The Advanced Integrated Wastewater Pond System (AIWPS) at Cal Poly San Luis Obispo and Living Machine installations are given as examples. Two examples of community-scale sewage treatment systems are also introduced.

The use of graywater, as a means of recycling water as a resource, is discussed. Water “grade” terms are presented: potable water, rainwater, graywater, blackwater, dark graywater, and clearwater. These classifications are explained and related to opportunities for on-site use of graywater. Subsurface irrigation is introduced as a component of graywater utilization. Stormwater treatment—as distinct from wastewater treatment—is discussed and related to site design decisions.

Chapter Outline

22.1 Waterless Toilets and Urinals
- (a) Composting toilets
- (b) Vault-type composting toilets
- (c) Heater-type composting toilets
- (d) Waterless urinals

22.2 Principles of Drainage
- (a) Traps
- (b) Vents
- (c) Air gaps and vacuum breakers

22.3 Piping, Fittings, and Accessories

(a) Piping and fittings
(b) Accessories
22.4 Design of Residential Waste Piping
22.5 Design of Larger-Building Waste Piping
(a) Basic planning
(b) Roughing-in
(c) The Sovent system
22.6 On-Site Individual Building Sewage Treatment
(a) Primary treatment: septic tanks
(b) Primary treatment: aerobic treatment units
(c) Secondary treatment: seepage pits
(d) Disposal fields
(e) Mounds with leaching beds
(f) Buried sand filters
22.7 On-Site Multiple-Building Sewage Treatment
(a) Open sand filters
(b) Recirculating sand filters
(c) Lagoons
(d) Advanced Integrated Wastewater Pond System (AIWPS)
(e) Constructed wetlands
(f) Greenhouse ecosystems
(g) Pasveer Oxidation Stream
22.8 Larger-Scale Sewage Treatment Systems
(a) Padre Dam Municipal Water District
(b) Oceanside Water Pollution Control Plant
22.9 Recycling and Graywater
(a) Graywater and future recycling
(b) Subsurface irrigation
22.10 Stormwater Treatment
References

Key Concepts

- waterless fixtures (toilets and urinals; an alternative approach)
- composting toilet (a waterless alternative)
- aerobic digestion (as a process type)
- anaerobic decomposition (as a process type)
- ventilation stack (as a necessary adjunct to some composting toilets)
- Clivus Multrum (a vault type composting toilet)
- Phoenix composting tank (a type of composting toilet)
- Sun-Mar (a type of heated composting toilet)
- BlueSeal (a waterless barrier to sewer gases)
- trap and vent (as crucial elements of a DWV system)
- piping “flag” (as a design visualization aid)
- distribution tree (as a design visualization aid—and recurring conceptual theme)
- drainage fixture unit (as a measure of required capacity)
- wet column (a design technique)
- rough-in (as a step in the construction process)
- primary, secondary, and tertiary treatment (for sanitary waste—sewage)
- filtration (seepage pit, drain field, mound, sand filter; as part of the treatment process)
- septic tank (as a common means of primary treatment)
- wetland (as a means of secondary/tertiary treatment—and a visible design feature)
- Living Machine (as a “mechanical” wetland and design opportunity)
- recycling (of water resources)
- graywater (as a grade of water quality)
- subsurface irrigation (as a usage for graywater)

- stormwater treatment (as distinct from sewage treatment)
- phytoremediation (extract, degrade, contain; as a means of stormwater treatment)

Chapter 23: Solid Waste

Summary: This chapter considers the issue of solid waste and building design. In-building provisions for the collection, sorting, and storage of solid wastes can consume substantial floor and chase space, may pose a fire hazard, and may affect indoor air quality if not properly designed.

The quantity of solid waste generated by day-to-day activities has increased substantially over the past 50 years. This trend has implications for the design of small and large buildings. A philosophy of viewing wastes as resources is suggested. These resources can be high-grade wastes (metals, wood, paper, plastics, or glass) suitable for recycling, or low-grade wastes that are suitable for combustion, digestion, or composting but not recycling. Recycling can save substantial energy in the production of further products, as illustrated by the production of aluminum, steel, and oriented strand board (OSB). An example of an integrated wastewater and solid waste processing facility at Cal Poly San Luis Obispo is presented.

Separation of solid waste into high- and low-grade materials can occur in a building (locally) or at some central waste-processing location. Each option has advantages and disadvantages, with local separation having the most impact on building design. Changes in culture (people's habits) and provision of appropriate spaces will need to accompany local separation. Audubon House in New York City is given as an example of a building that supports local separation.

In smaller buildings, a garbage disposal, garbage compactor, composting pile, and storage areas may be provided to assist in management of solid wastes and recovery of resources. In larger buildings a more elaborate procedure for handling solid wastes is likely to be required, with associated space and functional requirements. Trash compactors and vacuum conveyance systems are sometimes used in larger buildings. Service cores in larger buildings become a part of the solid waste handling process. In both large and small buildings, thought should be given to solid waste management during the design process.

Chapter Outline

Key Concepts

- waste as a resource (as a guiding philosophy for its handling)
- high-grade versus low-grade resources (as a conceptual organizing concept)
- separation (as a waste/resource management strategy)

- recycling (as a means of mining resources in waste)
- digestion (anaerobic and aerobic; waste-to-resource conversion processes)
- biogas (as a product of waste processing)
- composting (as a waste-to-resource conversion process)
- service core (as a key building design element)

Chapter 24: Fire Protection

Summary: Fire protection is a basic, yet wide-ranging and interdisciplinary, issue that involves specialized equipment and systems. This chapter, as a result, is extensive and diverse in its coverage. The systems and approaches addressed in this chapter fall under the realms of architectural, mechanical, and electrical design. Adding to this mix is the fact that fire protection is one of the most highly regulated aspects of building design and construction. Stepping back and holistically viewing the information presented—as part of the knowledge and tools needed to meet defined design objectives—should prove useful. There is a clear transition in the chapter between mechanical-architectural systems and electrical alarm systems.

Fire (combustion) is an energetic form of oxidation that can do great damage to buildings and occupants if it occurs uncontrolled. The “triangle of needs” establishes conditions for the development of fires. Sources of fire ignition include chemical, electrical, and mechanical activities and systems. A fire will emit products of combustion, including smoke (which includes carbon monoxide and carbon dioxide). Design for fire safety involves identification of the objectives (intent) for such design; protection of life, of property, and continuity of operations are the most common objectives. Codes, performance or prescriptive, provide minimum requirements (criteria) for fire protection. Fire protection systems (designed to deal with an extraordinary event) can and will interact with other building systems (designed to deal with day-to-day events). Fire protection systems may be active or passive.

Protection of life is generally the most important fire protection intent. Evacuation is a typical means of meeting this objective in low-rise buildings. Codes address this solution and minimum requirements have been developed involving egress width, exit access, exit discharge, smokeproof towers, and the like. Use of automatic suppression systems can modify basic code requirements. High-rise building evacuation is often very difficult and this has led to development of the refuge area concept.

Property protection can be enhanced through a number of design approaches, including access for firefighters, adequate and available water supplies, protection of exposures to external fire risks, compartmentalizing a building, taking care with concealed spaces, and protecting the structural system. Providing continuity of operations is more complex and often requires use of specialized alarm/suppression systems.

Smoke management has increased in importance as the role of smoke in fire deaths and damage has been clarified. Several factors enable the rapid spread of smoke throughout buildings, both low- and high-rise, and lead to sometimes counterintuitive design solutions. Confinement, dilution, and exhaust of smoke are discussed as elements of a smoke management system. The interaction of HVAC and sprinkler systems with smoke control solutions is considered.

Water is noted as the most popular medium for fire suppression; it is effective in many (but not all) fire situations. Getting water to the location of a potential fire is accomplished through the use of several systems. Standpipe and hose systems are commonly used as a manual fire suppression system. Several different classes (I, II, and III) and “types” (wet and dry pipe) of systems are examined. System components and performance characteristics are introduced. Automatic sprinkler systems can provide continuous fire suppression capabilities for a building. Characteristics, types, components, and performance aspects of sprinkler systems are presented. Selection of an appropriate system type and associated sprinkler heads are discussed. The concept of building “hazard” is introduced. Trends in sprinkler system application and design are explored. Mist systems are discussed. Portable fire extinguishers and applications (water and other) are presented.

Common fire suppression or control systems using media other than water are presented. These include the now-defunct Halon system, intumescent materials, inerting gases such as carbon dioxide, foams, and clean agent gases. Lightning protection is introduced, with a discussion of the effects of lightning, common system types, and typical components. Lightning arresters are also discussed.

Fire alarm system objectives, actions, devices, and applications are presented in substantial detail. Although such systems are diverse, they all involve a signal initiation, processing of the signal, and an alarm indication of some sort. Alarms can be manually or automatically initiated. A number of authorities play an active role in the design of fire alarm systems, including the National Fire Protection Association (NFPA), the American National Standards Institute (ANSI), the model code organizations (such as the ICC), Underwriters Laboratories, and insurance groups.

Fire alarm definitions and terms are defined and explained. Types of fire alarm systems are considered and classifications discussed. One such classification includes household fire warning, protected premises, and off-premises systems (including auxiliary, remote station, proprietary, central station, and municipal systems). Applications and components of each of these system types are presented.

Conventional systems are defined as those that use detectors or stations that transmit a signal only under alarm conditions. Characteristics of conventional systems and their devices are addressed. The concepts of threshold device, zoning, multiplexing, verification, coding, signal processing, and annunciation are presented. Several coding approaches are discussed. Addressable (as opposed to conventional) systems utilize addressable detection devices and involve ongoing communications between controls and devices. Analog devices are identified as those that provide a variable signal, but make no logical decision about alarm condition at the detector—reserving such decisions for the control system.

Automatic fire detection systems that function at each fire stage are discussed in detail. The fire stages are: incipient (ionization-type detectors), smoldering (photoelectric detectors), flame (ultraviolet or infrared detectors), and heat (thermal detectors). Characteristics and applications of the various detector types are presented. Specialized fire detectors are also considered. Guidelines for mitigating false alarms are given. Manual stations and sprinkler alarms are discussed, along with audible and visual alarm devices.

General recommendations for fire alarm systems are presented and followed with more specific recommendations for residential, multiple dwelling, commercial/institutional, high-rise office, and industrial occupancies.

Chapter Outline

FIRE RESISTANCE, EGRESS, AND EXTINGUISHMENT
24.1 Design for Fire Resistance
- (a) Sources of ignition
- (b) Products of combustion
- (c) Objectives in fire safety
- (d) Fire safety and other environmental control systems
- (e) Protection of life
- (f) Property protection
- (g) Continuity of operations

24.2 Smoke Management
- (a) Factors in smoke management
- (b) Confinement
- (c) Dilution
- (d) Exhaust
- (e) HVAC systems, sprinklers, and smoke
- (f) Automatic ventilating hatches

24.3 Water for Fire Suppression

(a) Standpipes and hoses
(b) Sprinkler system design impacts
(c) Sprinkler construction, orientation, and rating
(d) Sprinkler spacing and hazard
(e) Residential sprinklers
(f) Quick-response sprinklers
(g) Early suppression fast-response (ESFR) sprinklers
(h) Extended coverage sprinklers
(i) Future developments
(j) Wet-pipe systems
(k) Circulating closed-loop systems
(l) Dry-pipe systems
(m) Preaction systems
(n) Deluge systems
(o) Mist systems

24.4 Other Fire Suppression Methods

(a) The rise and fall of Halon 1301
(b) Foams
(c) Carbon dioxide (CO_2)
(d) Clean agent gases
(e) Portable fire extinguishers

24.5 Lightning Protection

(a) Franklin cone
(b) Overhead ground shield wire
(c) Faraday cage
(d) Lightning arresters
(e) High-rise buildings

FIRE ALARM SYSTEMS

24.6 General Considerations
24.7 Fire Codes, Authorities, and Standards
24.8 Fire Alarm Definitions and Terms
24.9 Types of Fire Alarm Systems

(a) Household fire warning systems
(b) Protected premises fire alarm system
(c) Auxiliary fire alarm system
(d) Remote-station protective signaling system
(e) Proprietary fire alarm system
(f) Central station fire alarm system

24.10 Circuit Supervision
24.11 Conventional Systems
24.12 System Coding

(a) Noncoded systems
(b) Master-coded systems
(c) Zone-coded systems
(d) Dual-coded systems
(e) Selective-coded systems
(f) Presignaling

24.13 Signal Processing
24.14 Addressable Fire Alarm Systems
24.15 Addressable Analog (Intelligent) Systems
24.16 Automatic Fire Detection: Incipient Stage
24.17 Automatic Fire Detection: Smoldering Stage

(a) Photoelectric smoke detection
(b) Projected beam photoelectric smoke detector
(c) Scattered light photoelectric smoke detector

(d) Laser beam photoelectric detector
(e) Air sampling detection system
(f) Application of photoelectric detectors
24.18 Automatic Fire Detection: Flame Stage
24.19 Automatic Fire Detection: Heat Stage
(a) Spot-type heat detectors
(b) Linear heat detectors
24.20 Special Types of Fire Detectors
24.21 False Alarm Mitigation
24.22 Manual Stations
24.23 Sprinkler Alarms
24.24 Audible and Visual Alarm Devices
(a) Audible signals
(b) Visible signals
(c) Strobe intensity
24.25 General Recommendations
24.26 Residential Fire Alarms
24.27 Multiple-Dwelling Alarm Systems
24.28 Commercial and Institutional Building Alarm Systems
24.29 High-Rise Office Building Fire Alarm Systems
24.30 Industrial Facilities
References

Key Concepts

- National Fire Protection Association (as a resource and arbiter for fire protection design)
- the “fire triangle of needs” (as an organizing principle)
- sources of ignition (chemical, electrical, mechanical; as the cause of building fires)
- products of combustion (as a design consideration)
- smoke (as related to—but, with respect to building design, distinct from—fire)
- fire safety objectives (as design intent)
- codes (performance-based or prescriptive; as a benchmark for minimum acceptable requirements)
- building (fire) hazard (as a design tool and consideration)
- passive versus active fire protection (design approaches)
- day-to-day versus emergency performance (as a design dichotomy)
- refuge area (as a design strategy)
- compartmentation (as a design strategy)
- smoke management (as a design issue/requirement)
- dilution (as a design strategy)
- exhaust (as a design strategy)
- water (as the most common fire suppressant)
- standpipe and hose system (as a design solution)
- automatic sprinkler system (as a design solution)
- sprinkler head (as the interface between system performance and appearance)
- residential sprinklers (as a growing trend)
- portable fire extinguisher (as a design solution)
- fire classes (A, B, C, and D; as a design consideration)
- lightning protection and options (as a design decision/solution)
- fire alarm system (as a design issue/requirement)
- manual or automatic (as fire alarm initiation options)
- fire code, authority, standard (as sources of fire protection and alarm requirements)
- fire stage (as a design consideration and system/device selection tool)
- devices (initiators, processors, indicators; as design elements)
- detectors (as a class of fire protection system devices)

Chapter 25: Principles of Electricity

Summary: This chapter is the first of several that deal with building electrical systems. As noted by the authors, electricity is the most prevalent form of energy in today's buildings and knowledge of its properties, delivery, and usage is beneficial to the building designer.

Electricity is characterized as a form of energy that is not terribly useful in its natural forms (lightning and galvanic action), but which has proven invaluable in its manufactured forms. Electricity is comprised of electrons flowing in a circuit. The flow is called a current (measured in amperes). Direct and alternating current (dc and ac) systems are available, with alternating current predominating in building applications. DC systems are encountered when batteries or photovoltaic cells are used. The tendency for electrons to flow is termed potential or voltage (measured in volts). Resistance to current flow is termed resistance (in dc circuits) or impedance (in ac circuits) and is measured in ohms. Ohm's Law defines the relationship between voltage, current, and resistance in a circuit.

Circuits may be arranged in series (with elements connected one after another) or in parallel (with elements connected via branches to/from the same points). Parallel circuits are standard for all building wiring. In a parallel circuit loads are additive with respect to current, and each load experiences the same voltage. A short circuit occurs if an inadvertent connection appears across the circuit, with potentially damaging results. AC electricity can be generated at different frequencies; 60 Hertz (cycles per second) is the standard in North America.

AC power generation is briefly discussed. The difference between power and energy is emphasized and noted as a commonly misunderstood distinction. Units of measurement for power and energy are described and the concept of power factor introduced. Sample calculations for power, energy, and electricity costs are provided. Load factor and demand charge are explained. Typical electric demand control approaches are reviewed. The distinction between demand control and energy management is emphasized. Meters and measurements for electric systems are discussed.

Chapter Outline

25.1 Electric Energy
25.2 Unit of Electric Current—The Ampere
25.3 Unit of Electric Potential—The Volt
25.4 Unit of Electric Resistance—The Ohm
25.5 Ohm's Law
25.6 Circuit Arrangements
- (a) Series circuits
- (b) Parallel circuits

25.7 Direct Current and Alternating Current
25.8 Electric Power Generation—DC
25.9 Electric Power Generation—AC
25.10 Power and Energy
25.11 Power in Electric Circuits
25.12 Energy in Electric Circuits
25.13 Electric Demand Charges
25.14 Electric Demand Control
- (a) Level 1—load scheduling and duty-cycle control
- (b) Level 2—demand metering alarm
- (c) Level 3—automatic instantaneous demand control
- (d) Level 4—ideal curve control
- (e) Level 5—forecasting systems

25.15 Electrical Measurements

Key Concepts

- electricity (as the preeminent energy source for buildings)
- electric current (describing the flow of electricity)
- alternating and direct current (as two forms of electricity)
- voltage or potential (as the driving mechanism for electricity)
- conductor or insulator (as opposing sets of properties)
- Ohm's Law (as it relates current, voltage, and resistance)
- parallel and series circuits (as distribution options)
- energy and power (as critical concepts)
- demand control (as a design strategy—and distinct from energy management)

Chapter 26: Electrical Systems and Materials: Service and Utilization

Summary: This chapter addresses the components of a building electrical system that handle and condition power. Options for incoming electrical service are reviewed. Such service, overhead or underground, must comply with the *National Electrical Code*, applicable local code requirements, and requirements of the local utility. Issues to consider when selecting a type of service and associated conductors are considered. Advantages and disadvantages of overhead and underground service are given.

A number of electrical components fall under the category “service equipment.” A transformer is such a component. Transformers are used to change voltage, typically to reduce service voltage to an appropriate utilization voltage (step-down) —but they can also be used to increase voltage (step-up). The output voltage is termed secondary, the input voltage primary. Transformers only work on AC current. Transformer power capacity is rated in kilovolt-amperes. Transformers come in a range of designs and capacities, and may be installed within or outside of a building. The means of cooling (dry or liquid) will influence location and may impose special space design requirements. Energy efficiency of transformers is an issue to consider. Selection issues are discussed.

The arrangement of service equipment is covered and metering is discussed. A service switch will be provided to disconnect the building from the utility service. Other switches will also be employed throughout an electrical system—most common are general duty safety switches. A contactor is often used for switching purposes and permits a range of remote control operations. If electrically actuated, a contactor is called a relay. Special purpose switches include latching remote control switches, automatic transfer switches, and time-controlled switches. Solid state switches are seeing increased usage for automatic control purposes—as time controlled electronic switches, programmable time switches, and programmable controllers. Equipment enclosure is an important design issue.

Circuit protective devices play a critical role in the provision of safe electrical systems. Fuses and circuit breakers are typical protective devices. Protection is necessary against overloads, short circuits, and ground faults. Fuses (cartridge and plug) are one-time-use devices, but have a great range of application capabilities. Circuit breakers (molded case and large air breakers) are resettable devices, but have a more limited range of applications than fuses. Characteristics and advantages/disadvantages of fuses and circuit breakers are reviewed in detail.

Switchboards (or switchgear) are free-standing assemblies of switches, fuses, circuit breakers, and (sometimes) meters that serve a number of circuits. When equipped with molded case breakers, switchgear is often referred to as a “building-type switchboard.” Switchgear may be installed inside or outside of a building, although special consideration to weatherproofing must be given to exterior installations. An assembly combining primary and secondary switches, transformer, protective devices, controls, and meters is known as a unit substation or load-center substation.

Panelboards (or electrical panels) provide the same general functions as a switchboard but are installed further into the distribution system. Panelboards typically feed branch circuits. Smaller panels are often called load centers. The importance of load control to limiting electrical demand and thereby to energy conservation is emphasized. An “intelligent” panelboard can provide some load control functions.

Electric motors are an important load element in many buildings. Motor applications are reviewed, including a discussion of motor types. AC squirrel-cage motors are most prevalent in building equipment and are examined in some detail. A review of nameplate data is used to introduce key motor characteristics. Premium efficiency motors are available. Motor control is an important aspect of electrical system design. Basic control using a starter (manual or automatic; across-the-line full voltage or reduced voltage) can stop, start, and protect a motor from overload.

It is noted that motor speed control equipment is readily available and is being used more commonly. Variable-voltage, variable-frequency (VVVF) controllers (also known as variable frequency drives—VFD) can provide good control. A motor control center can be used when several motors are installed in proximity to one another.

Wiring devices are described as a class of device that is normally installed in wall outlet boxes. These include receptacles, switches, dimmers, etc. Quality grades for such devices are explained. Receptacles (duplex convenience receptacle outlet) are a common wiring device. Ground-fault circuit interrupter receptacles (GFIC) are available, as are surge suppressor and isolated ground receptacles. Receptacle, switch, and specialty device nomenclature and applications are covered. Low-voltage switching and wireless switching/control are presented as options. Power line carrier control systems are introduced.

Power conditioning is discussed in detail. The need for such conditioning is increasing as data and communications systems become common features in many building types. Disturbances on power lines can include voltage variations (relatively slow changes), electrical noise, and transients (surges or spikes). Voltage regulators can address voltage variations; electrical isolation, filters, and noise suppressors can address noise; surge suppressors can address transients. General recommendations for power conditioning applications are given. The importance of power quality in modern commercial facilities is emphasized. Typical power conditioning equipment is reviewed and necessary terminology presented. It is noted that the quality of transmission on telephone and data lines must also be protected.

Uninterruptible power supply (UPS) systems are discussed and compared to emergency and standby power systems. Power sources, equipment arrangements, and operation strategies for UPS systems are considered. System selection is discussed. The difference between emergency and standby power systems is emphasized. Engine-generator and battery sources are reviewed. The inspection of the entire electric system during construction is outlined.

Chapter Outline

26.1 Electric Service
26.2 Overhead Service
26.3 Underground Service
26.4 Underground Wiring
26.5 Service Equipment
26.6 Transformers
26.7 Transformers Outdoors
26.8 Transformers Indoors: Heat Loss
26.9 Transformers Indoors: Selection
- (a) Oil-insulated transformers
- (b) "Less-flammable" liquid-insulated transformers
- (c) Non-flammable fluid-filled transformers
- (d) Dry-type transformers

26.10 Transformer Vaults
26.11 Service Equipment Arrangements and Metering
26.12 Service Switch(es)
26.13 Switches
26.14 Contactors
26.15 Special Switches
- (a) Remote-control (RC) switches
- (b) Automatic transfer switch
- (c) Time-controlled switches

26.16 Solid-State Switches, Programmable Switches, Microprocessors, and Programmable Controllers
26.17 Equipment Enclosures

26.18 Circuit-Protective Devices
(a) Fuses
(b) Circuit breakers
(c) Characteristics of fuses and circuit breakers
26.19 Switchboards and Switchgear
26.20 Unit Substations (Transformer Load Centers)
26.21 Panelboards
26.22 Principles of Electric Load Control
26.23 Intelligent Panelboards
26.24 Electric Motors
(a) Direct-current motors
(b) Alternating-current motors
(c) Squirrel-cage induction motors
(d) Electric motor energy considerations
26.25 Motor Control Standards
26.26 Motor Control
(a) Fundamentals
(b) Motor speed control
26.27 Motor Control Equipment
26.28 Wiring Devices: General Description
26.29 Wiring Devices: Receptacles
26.30 Wiring Devices: Switches
26.31 Wiring Devices: Specialties
26.32 Low-Voltage Switching
26.33 Wireless Switching and Control
26.34 Power Line Carrier Systems
26.35 Power Conditioning
(a) General information
(b) Source of disturbance
26.36 Power Conditioning Equipment
26.37 Surge Suppression
(a) Terminology
(b) TVSS operation
(c) Standards
(d) Application of TVSS devices
26.38 Uninterruptible Power Supply
(a) Alternate power source
(b) Equipment arrangement: classic standby and on-line topologies
(c) Additional UPS topologies
(d) System selection and comparison
(e) Ancillary characteristics of UPS systems
26.39 Emergency/Standby Power Equipment
(a) Engine-generator sets
(b) Battery equipment
26.40 System Inspection

Key Concepts

- electric service and service options (from the utility provider)
- transformer (as a main item of electrical equipment)
- primary and secondary voltages (as design issues and decisions)
- transformer characteristics (as they affect design decisions)
- service switch (as an item of electrical safety equipment)
- switches (as a diverse means of equipment/system control)
- circuit protective devices (as a key electrical circuit safety element)
- switchboard (as a main item of electrical equipment)

- substation (as a main item of electrical equipment)
- panelboard (as a key item of electrical equipment)
- load control (as a design and operation strategy)
- motor control (as a design consideration)
- wiring devices (receptacles, etc.—as a design issue of type and location)
- power conditioning (as a growing concern in buildings)
- uninterruptable power supply (UPS—as a growing technology in buildings)
- emergency versus standby power system (as a design/code consideration)
- system inspection (as a part of the construction [and commissioning] process)

Chapter 27: Electrical Systems and Materials: Wiring and Raceways

Summary: This chapter explores the carriers (conductors, protection, and support) by which electricity is distributed to building loads. Design and selection of components for these wiring and raceway systems is defined by the *National Electrical Code* (NEC) and by Underwriters Laboratories (UL) listings. Electrical equipment is rated according to its normal service expectations; ratings include voltage, current, temperature, etc. Decisions as to distribution system type and appropriate materials are governed by codes, suitability to function, aesthetics, and economics. Life-cycle cost analysis of design options is sometimes warranted and typically involves energy considerations.

Wiring systems are referred to according to their primary purpose: distribution of electrical power or distribution of electrical signals or communications. Power system design focuses upon safety, which is enhanced by isolation provided by insulation and protective elements. Several types of interior wiring systems are presented. In general these systems include: exposed insulated cables (commonly used and "self-contained"), insulated cables in open raceways (typical of industrial applications), and insulated conductors in closed raceways (covering a wide range of options for a range of facility types). Integral assemblies that combine conductor and enclosure are also available.

Conductors, copper or aluminum, are sized using the AWG (American Wire Gauge) or kcmil (thousand circular mil) designations. AWG sizes decrease with increasing number; kcmil sizes increase with increasing number. The term "wire" is applied to conductors No. 8 AWG or smaller. The term "cable" applies to larger conductors or any fabricated assembly of multiple wires. The current-carrying capacity of a conductor is rated by ampacity and is fundamentally a function of size, operating temperature, and insulation type. Insulations ensure electrical isolation of conductors and are rated by voltage and permissible temperature. Numerous insulations are used. Jackets are sometimes provided to afford physical shielding. The relative merits of copper and aluminum conductors are discussed.

A detailed review of conductor options is provided. "Building wire" consists of a range of general purpose insulated conductors. Flexible armored cable (BX) is a commonly used exposed wiring type with conductors and steel tape protective covering. Metal-clad cable (MC) is more robust and has a wider range of potential applications. Nonmetallic sheathed cable (Romex) is commonly used in small buildings. Other cable types are available for special applications.

Busway (or busduct) and cablebus comprise a group of assemblies that are applied where heavy current loads are encountered. Busway/busduct consists of a housed assembly using conductor bars (versus cables). "Plug-in" busduct permits loads to be easily connected using plug-in connector devices. Cablebus uses cables instead of conductor bars. These systems are typically used for feeders and risers. Light-duty plug-in busways are also available. Flat cable assemblies comprise a special cable installed in a field-mounted channel; power tap devices are installed as needed on the channel and make electrical connection with the cable when installed. Lighting track is used to power movable lighting fixtures; non-lighting loads may not be served.

A cable tray is simply a continuous open raceway/support for conductors. Considering closed raceways, there is a wide range of options open to the designer. The chapter focuses upon power raceways, but it is noted that communication raceway requirements may now far exceed those for power distribution. General design considerations for communications raceways are given. Many closed raceway system types involve installation (such as an in-slab location) that must be considered early in the design process.

Conduit is introduced as a form of raceway. Steel conduit is the basic type and the purposes behind its use are discussed. Heavy-wall (rigid steel) conduit, intermediate metal conduit (IMC), and electrical metal tubing (EMT) are defined, described, and compared. Aluminum conduit is considered. Characteristics and applications of flexible metal conduit (Greenfield and Sealtite) and nonmetallic conduit are presented. Surface metal raceway characteristics and applications are discussed. Outlet and device boxes are addressed. Proper treatment of electrical penetrations through floors (and other rated constructions) is emphasized.

Floor raceways are available in numerous configurations. The options for such raceways are summarized: underfloor raceways, cellular metal floor raceways, and cellular concrete floor raceways. Each of the raceway types is discussed in detail with consideration of installation, utilization, and applications. Each may be used for power and/or data communications distribution (when properly designed). Criteria for consideration of underfloor duct systems are presented. A full access floor is a specialized approach to floor distribution. Under-carpet wiring systems are a manufactured system for floor distribution. Ceiling raceways and manufactured wiring systems may also be considered; they are introduced and their characteristics summarized.

Chapter Outline

27.1 System Components
27.2 National Electrical Code
27.3 Economics of Material Selection
27.4 Energy Considerations
27.5 Electrical Equipment Ratings
- (a) Voltage
- (b) Current

27.6 Interior Wiring Systems
- (a) Exposed insulated cables
- (b) Insulated cables in open raceways (trays)
- (c) Insulated conductors in closed raceways
- (d) Combined conductor and enclosure

27.7 Conductors
27.8 Conductor Ampacity
27.9 Conductor Insulation and Jackets
27.10 Copper and Aluminum Conductors
27.11 Flexible Armored Cable
27.12 Nonmetallic Sheathed Cable (Romex)
27.13 Conductors for General Wiring
27.14 Special Cable Types
27.15 Busway/Busduct/Cablebus
27.16 Light-Duty Busway, Flat-Cable Assemblies, and Lighting Track
- (a) Light-duty plug-in busway
- (b) Flat-cable assemblies
- (c) Lighting track

27.17 Cable Tray
27.18 Design Considerations for Raceway Systems
27.19 Steel Conduit
27.20 Aluminum Conduit
27.21 Flexible Metal Conduit
27.22 Nonmetallic Conduit
27.23 Surface Metal Raceways (Metallic and Nonmetallic)
27.24 Outlet and Device Boxes
27.25 Floor Raceways
27.26 Underfloor Duct
27.27 Cellular Metal Floor Raceway
27.28 Precast Cellular Concrete Floor Raceways
27.29 Full-Access Floor
27.30 Under-Carpet Wiring System

27.31 Ceiling Raceways and Manufactured Wiring Systems

Key Concepts

- power distribution system (as a system type and design consideration)
- conductor (as a means of transmitting electricity)
- wiring assemblies (as options for distribution systems)
- wiring locations (as an issue to be addressed early in the design process)
- *National Electrical Code* (as a source of minimum requirements and design standards)
- safety (as the objective of electrical codes and a design intent)
- life-cycle cost analysis (as a design decision tool)
- electrical power versus electrical signal or communication system (as a design distinction)
- equipment ratings (as a selection parameter)

Chapter 28: Electric Wiring Design

Summary: This chapter addresses the topic of electrical wiring design within the context of design criteria that provide for appropriate performance within the safety requirements established by codes. As there are numerous acceptable solutions for most design situations, general guidelines and suggestions from practice are often provided. Conformance to local code requirements is emphasized.

General considerations that will influence wiring system design include: expectations for flexibility, a desire for reliability, demands for safety, first cost and life-cycle cost considerations, and energy conservation requirements and desires. Space availability and requirements for systems installation and maintenance must be considered. Any special circumstances pertaining to a given facility also need to be identified.

The wiring design process generally starts with an estimate of building electrical load. Data tables and suggestions to assist in this process are provided. Building electrical loads may be categorized as follows: lighting, miscellaneous power, HVAC, plumbing/piping, vertical transportation, kitchen equipment, special equipment. The magnitude of loads in each category will vary from building type to building type.

System voltage selection will greatly influence wiring design. System voltage is the voltage capability provided by the utility service or building transformer. Several standard system voltage and wiring arrangements are in use in North America and include: 120 volt, 1-phase, 2-wire; 120/240 volt, 1-phase, 3-wire; 120/208 volt, 1-phase, 3-wire; 120/208 volt, 3-phase, 4-wire; 277/480 volt, 3-phase, 4-wire; and 2400/4160 volt, 3-phase, 4-wire. Typical applications for each of these arrangements are discussed. Transformer voltage standards establish system voltages, motor voltage standards establish utilization voltages; the two are in reasonable agreement.

Grounding and ground-fault protection are discussed in some detail, including background and typical practices. Energy conservation considerations are also surveyed. General design procedures that will lead to energy-conserving designs are outlined.

A generic step-by-step process applicable to the design of wiring for a range of facility types is presented. The process proceeds from load estimating, to equipment placement and sizing, to wire sizing for branches and feeders, and concludes with drawings and coordination. Location of electric spaces (including electric closets), the properties of such spaces, and the effect of circuit lengths resulting from location decisions are discussed. Equipment layout and the development of lighting and power drawings are explored. General rules for the application of overcurrent protection equipment are reviewed.

Rules of good practice for the design of branch circuits are presented and discussed. Guidelines for branch circuits in residential and nonresidential (school and office) occupancies are considered in substantial detail. Rules of practice for tabulating panel loads are presented. The concepts of demand factor and spare capacity are introduced. Feeder capacity and sizing is discussed and illustrated by worked examples. Voltage drop is considered. The development of riser diagrams is discussed. The importance of coordination in the development of electrical systems is emphasized. A caution is given regarding the use of computer programs for sizing calculations.

Harmonic currents (as an element of power quality) are described as a growing problem in modern buildings. Although the issue of harmonics is complex, an overview of the problem and potential solutions is given. Passive solutions have historically been employed, but there is movement to active solutions such as “active line conditioning.” The need for—and relationships between—emergency, legally required standby, and optional standby systems is explored. Reliability is distinguished from “emergency.”

Chapter Outline

28.1 General Considerations
- (a) Flexibility
- (b) Reliability
- (c) Safety
- (d) Economic factors
- (e) Energy considerations
- (f) Space allocations
- (g) Special considerations

28.2 Load Estimating
28.3 System Voltage
- (a) 120-V, single-phase, 2-wire
- (b) 120/240-V, single-phase, 3-wire
- (c) 120/208-V, single-phase, 3-wire
- (d) 120/208-V, 3-phase, 4-wire
- (e) 277/480-V, 3-phase, 4-wire
- (f) 2400/4160-V, 3-phase, 4-wire

28.4 Grounding and Ground-Fault Protection
28.5 Energy Conservation Considerations
28.6 Design Procedure
28.7 Electrical Equipment Spaces
- (a) Residences
- (b) Commercial spaces

28.8 Electrical Closets
28.9 Equipment Layout
28.10 Application of Overcurrent Equipment
28.11 Branch Circuit Design
28.12 Branch Circuit Design Guidelines: Residential
28.13 Branch Circuit Design Guidelines: Nonresidential
- (a) Schools
- (b) Office space
- (c) Industrial spaces
- (d) Stores

28.14 Load Tabulation
28.15 Spare Capacity
28.16 Feeder Capacity
28.17 Panel Feeder Load Calculation
28.18 Harmonic Currents
28.19 Riser Diagrams
28.20 Service Equipment and Switchboard Design
28.21 Emergency Systems
- (a) General information
- (b) NFPA codes
- (c) Technical considerations

References

Key Concepts

- design criteria (as benchmarks for design decisions and analyses)
- flexibility (as an important design objective)
- reliability (as an important design objective)
- safety (as a mandatory design consideration)
- economic factors (as a decision-making tool)
- energy conservation (as a societal and personal design objective)
- space allocations and locations (as design issues throughout the design process)

- load estimating (as a design tool)
- service versus system versus utilization voltages (as design issues)
- electrical system design process (should be understood for coordination purposes)
- harmonics (as a growing power quality problem)
- reliability, emergency, and standby (as distinct design considerations)

Chapter 29: Photovoltaic Systems

Summary: Photovoltaic (PV) generation of electricity is becoming more common in the building sector as PV costs have come down and interest in "green" energy alternatives has gone up. Typical PV costs are indicated as $1.50-2.50 per watt of capacity and $0.50-0.25 per watt produced. Net-metering regulations for power "buy-back," utility interest in alternative power sources, several federal government programs, and the advent of building-integrated photovoltaic options are noted as trends encouraging the use of PV systems. PV systems may be designed as stand-alone or as grid-connected systems; a hybrid stand-alone system is also described. Direct connected systems feed power directly to loads without the provision of storage; these systems are noted as being rarely used. Battery storage permits system output to better match building loads across time. Grid-connected PV systems permit a building to use either PV or utility-generated power to meet building loads.

Codes and standards that will affect the design of photovoltaic systems are reviewed. Terminology and definitions applicable to PV systems are explained. The difference between irradiance and insolation is emphasized; the elements of a PV system are described; types of PV cells are defined. The photovoltaic effect is discussed in some detail and conversion efficiencies for PV cells outlined. Older large-crystal silicon cells are compared to newer polycrystalline, thin-film, amorphous cells. Fixed versus tracking arrays are discussed. Battery types appropriate for use in PV systems are examined in detail, including performance characteristics and capacity ratings.

The design process for a stand-alone PV system is described and illustrated by means of a worked example. A different design process applicable to a grid-connected system is also described. Various examples of PV applications are presented.

A case study of the Lillis Business Complex at the University of Oregon is provided as an example of a recent building-integrated photovoltaic application. The case study provides context and background for the project (including design intent, criteria, and validation approaches). Key building design features are described.

Chapter Outline

Key Concepts

- photovoltaic or PV (as a "green" means of generating electricity)
- net metering (as a photovoltaic power billing approach)

- stand-alone versus grid-connected PV systems (as alternative design approaches)
- avoided cost (as a means of establishing utility payments for PV power)
- PV system terminology (as a means of fostering design team communication)
- insolation versus irradiance (as distinct metrics of solar availability)
- photoelectric effect (the reason PV cells generate electricity)
- building-integrated photovoltaics or BIPV (as an emerging PV installation trend)

Chapter 30: Signal Systems

Summary: This chapter addresses the application of signal systems in a variety of building types. Typical elements of the most common signal systems are introduced and their arrangements and applications in different building contexts are explored. The focus is upon system usage and coordination, not upon detailed system design. The term signal system is defined to include signal, communication, and control systems.

Principles of intrusion detection are presented. Intrusion systems include detector, processing, and annunciation elements. Several types of detectors are available: mechanical motion detectors, photovoltaic devices (visible, infrared, and laser), passive infrared presence detectors, ultrasonic or microwave motion detectors, and acoustic detectors. Intrusion control and access control are differentiated.

The discussion of applications is generally cumulative, with several basic applications falling under several building types. Signal system applications in single-family residences are reviewed and illustrated. Such applications typically include: intrusion alarm, intercom, and telecommunication and data systems. The idea of “premise wiring” is presented. Applications noted for multiple-dwelling facilities include entry and security, television/cable, and telephone systems. Motel/hotel systems include security and telecommunications/data.

School signal systems discussed include: security, clock and program, intercom, sound, and electronic teaching equipment. Office building systems presented include security, communications, and automation and control. Planning considerations for office telecommunications systems are presented. Applications to industrial facilities address the special character of such facilities; access control systems are included.

Stand-alone and integrated control systems are distinguished. Building automation is discussed in general. Building automation system arrangements are reviewed and illustrated. Possibilities for “intelligent” buildings, residential and non-residential, are explored. A detailed glossary of computer and control terminology is presented.

Chapter Outline

30.1 Introduction
30.2 Principles of Intrusion Detection
- (a) Sensors with normally open (NO) contacts
- (b) Simple normally closed (NC) contact sensors
- (c) Mechanical motion detectors
- (d) Photoelectric devices
- (e) Passive infrared (PIR) “presence” detector
- (f) Motion detectors
- (g) Acoustic detectors

PRIVATE RESIDENTIAL SYSTEMS
30.3 General Information
30.4 Residential Intrusion Alarm Systems
30.5 Residential Intercom Systems
30.6 Residential Telecommunication and Data System
30.7 Premise Wiring

MULTIPLE-DWELLING SYSTEMS
30.8 Multiple-Dwelling Entry and Security Systems
30.9 Multiple-Dwelling Television Systems
30.10 Multiple-Dwelling Telephone Systems
30.11 Hotels and Motels

(a) Security
(b) Telecommunication, data

SCHOOL SYSTEMS
30.12 General Information
30.13 School Security Systems
30.14 School Clock and Program Systems
30.15 School Intercom Systems
30.16 School Sound Systems
30.17 School Electronic Teaching Equipment
(a) Passive-mode usage
(b) Interactive mode

OFFICE BUILDING SYSTEMS
30.18 General Information
30.19 Office Building Security Systems
30.20 Office Building Communications Systems
30.21 Office Building Communications Planning
(a) Service entrance
(b) Riser shafts
(c) Riser closets
(d) Satellite closets
(e) Auxiliary equipment rooms
(f) Horizontal distribution
(g) FO cables
30.22 Office Building Control and Automation Systems

INDUSTRIAL BUILDING SYSTEMS
30.23 General Information
30.24 Industrial Building Personnel Access Control
30.25 Industrial Building Sound and Paging Systems

AUTOMATION
30.26 General Information
30.27 Stand-Alone Lighting Control Systems
30.28 Building Automation Systems
30.29 Glossary of Computer and Control Terminology
30.30 BAS Arrangement
30.31 Intelligent Buildings
30.32 Intelligent Residences

Key Concepts

- signal system applications versus signal system design (an architectural design concern)
- signal, communication, and control functions (all grouped under the "signal system" heading)
- system space requirements (vary from system to system, but must be considered early in design)
- system wiring requirements (pre-planning for distribution is critical)
- intrusion detection (as a signal function)
- access control (as a signal function)
- intercom (as a signal function)
- telecommunication and data (as a burgeoning signal function)
- telephone (as a signal function)
- television/cable (as a signal function)
- security (as a signal function)

- clock and program system (as a signal function)
- sound distribution (as a signal function)
- electronic teaching equipment (as a burgeoning signal function)
- premise wiring (as a common signal system terminology)
- remote versus automatic system actuation (as worthy of distinction)
- building automation system arrangements (as design implementation options)
- intelligent building (as an emerging concept)
- common functions in different contexts (as a linking thread for signal systems)

Chapter 31: Vertical Transportation: Passenger Elevators

Summary: This chapter is the first of three chapters dealing with mechanized transportation systems for buildings. The focus of the chapter is traction elevators for passenger use. Design criteria and system performance indicators are explained. In a tall building, elevators can become a major part of construction cost and can have a dramatic impact on occupant satisfaction. Although the chapter emphasis is new designs, rehabilitation of existing systems is briefly discussed.

An ideal elevator system provides minimum waiting time for users, comfortable acceleration and deceleration, speedy trips, accurate landings, and comfortable loading/unloading. Users should experience a secure, reliable, pleasant, and understandable transportation system. The ANSI *Safety Code for Elevators and Escalators* addresses elevator safety concerns. ASME and local codes, and the NFPA *Life Safety Code*, may also apply. ADA requirements for elevators are summarized.

The primary components of an elevator system comprise the cars, supporting cables, counterweights, elevator machine (motor) and sheave, shaft(s) or hoistway(s), an elevator machine room, and controls. Controls include drive control (for an individual car), operating control (the interface with users), and supervisory control (for group operations). Gearless traction machines are typically used for medium- to high-speed applications (500 fpm and higher); geared traction machines are typically used for low-speed (less than 500 fpm) applications. The gearless machine is considered superior from an operational viewpoint. Several arrangements of machine (motor), sheave, and roping are available. Dual safety systems are typically employed.

There are several car, door, and signal arrangements available. In addition, there are several common car control systems that may be considered—these include ac and dc thyristor control, variable voltage dc motor control (also known as Ward-Leonard), and the high-performance variable-voltage, variable-frequency ac motor control system. Overall control of an elevator system may take several forms: simple single automatic pushbutton control, collective control, selective collective control, and substantially more sophisticated computerized control systems. Features typical of computerized controls are discussed. The functions of the lobby control panel and car operating panel are addressed.

The process of selecting an appropriate arrangement of elevators for a variety of building types is reviewed. Selection criteria are defined and explained and the relationships between system variables are explored. The selection process is illustrated by worked examples. Key design criteria include: interval, average waiting time, handling capacity, and travel time. Additional criteria/performance indicators include registration time and round-trip time. Recommendations for the establishment of selection criteria are provided along with charts of typical performance values. Considerations for specific occupancies (office, apartment, hospital, and retail) are provided.

Single and multiple zone elevator systems are described. Spatial requirements and physical organization of elevator systems are discussed—including lobby and shaft layouts. The availability from manufacturers of "standard elevator layouts" is noted.
Power and energy requirements for elevator operation are considered. Sample calculations are provided. Energy conservation is addressed. Special considerations—such as emergency power, fire safety, security, and noise—are described.

Chapter Outline

ELEVATOR EQUIPMENT
31.4 Principal Components
31.5 Gearless Traction Machines
31.6 Geared Traction Machines
31.7 Arrangement of Elevator Machines, Sheaves, and Ropes
31.8 Safety Devices
31.9 Elevator Doors
31.10 Cars and Signals
31.11 Requirements for the Disabled

ELEVATOR CAR CONTROL
31.12 Drive Control
31.13 Thyristor Control, AC and DC
(a) ac
(b) dc
31.14 Variable-Voltage DC Motor Control
31.15 Variable-Voltage, Variable-Frequency AC Motor Control
31.16 Elevator Operating Control
31.17 System Control Requirements
31.18 Single Automatic Pushbutton Control
31.19 Collective Control
31.20 Selective Collective Operation
31.21 Computerized System Control
31.22 Rehabilitation Work: Performance Prediction
31.23 Lobby Elevator Panel
31.24 Car Operating Panel

ELEVATOR SELECTION
31.25 General Considerations
31.26 Definitions
31.27 Interval or Lobby Dispatch Time and Average Lobby Waiting Time
31.28 Handling Capacity
31.29 Travel Time or Average Trip Time
31.30 Round-Trip Time
31.31 System Relationships
31.32 Car Speed
31.33 Single-Zone Systems
31.34 Multizone Systems
31.35 Other Elevator Selection Recommendations
(a) Office buildings
(b) Apartment buildings
(c) Hospitals
(d) Retail stores

PHYSICAL PROPERTIES AND SPATIAL REQUIREMENTS OF ELEVATORS
31.36 Shafts and Lobbies
31.37 Dimensions and Weights
31.38 Structural Stresses

POWER AND ENERGY
31.39 Power Requirements
31.40 Energy Requirements
31.41 Energy Conservation
31.42 Emergency Power

SPECIAL CONSIDERATIONS
31.43 Fire Safety
31.44 Elevator Security
    (a) Rider security
    (b) Access control
31.45 Elevator Noise
31.46 Elevator Specifications
    (a) Owner's responsibility
    (b) Elevator contractor's responsibility
    (c) Special job conditions
31.47 Novel Designs
References

Key Concepts

- quality of elevator service (as a tenant/occupant retention issue)
- codes and standards (as an external influence on design)
- elevator system components (as a means of understanding design/operation of system)
- gearless traction machine (as a preferred choice for medium- and high-speed systems)
- geared traction machine (as a choice for low-speed systems)
- layers of control in elevator system (as a design consideration)
- safety systems (as a user concern and code issue)
- elevator system design criteria (as a measure of need and indicator of capability)
- interrelationship of elevator performance metrics (as a design and evaluation tool)
- zoning (as a design tool)
- service (freight) versus passenger cars (as a design decision)
- shaft and lobby design (as a determinant of performance/satisfaction; as a space issue)
- fire and smoke control issues (as a design coordination concern)
- rider safety and access control (as design considerations)
- energy and power relationships (a distinction to be understood)

Chapter 32: Vertical Transportation: Special Topics

Summary: This chapter covers a somewhat eclectic collection of vertical transportation topics: hydraulic elevator systems, residential elevator applications, innovative elevator systems, and material-handling systems.

Shaft space for elevators has a major impact on efficiency of space use. Sky-lobby and double-deck elevator systems represent attempts to reduce the impact of elevator shaft requirements on building space efficiency while retaining acceptable performance.

Hydraulic elevators employ a plunger as the motive force, versus the rotating action of a motor and associated cables employed with traction elevators. Hydraulic elevator designs include the conventional plunger-type (requiring a hole below the elevator pit), the hole-less type (using a telescoping plunger), and the roped hydraulic type (in which roping reduces the plunger travel requirements). Advantages of hydraulic elevators include the absence of an overhead machine room (penthouse), the fact that loads are carried directly by the ground (instead of structural members), virtually unlimited load capacity, and a somewhat smaller shaft space requirement. Primary disadvantages of hydraulic elevators include slow speeds, a limitation to low rise installations, and somewhat inferior ride quality relative to traction machines.

Freight elevator design considerations are introduced and components and systems reviewed. The main design issues include: size, weight, nature, and frequency of loads; travel patterns; means of loading; and elevator car characteristics (doors, speed, capacity). Freight elevators are classified by ANSI into five load classifications (A, B, C1, C2, C3). Geared traction (with VVVF or umv controls) and hydraulic drives are most commonly used. Relative cost data for freight elevators are given.

Special elevator designs are briefly addressed. These include systems with observation cars, inclined elevators, rack and pinion drives, and linear motor drives. Residential elevators and chair lifts are considered in some detail, with examples of equipment and installations.

Material-handling systems are reviewed. The general need for such systems in buildings is discussed. Typical systems and applications are presented. These include: manual load/unload dumbwaiters, automated dumbwaiters, horizontal and vertical conveyors, pneumatic tubes of various types, automated container delivery, and self-propelled vehicles.

Chapter Outline

32.12 Inclined Elevators
32.13 Rack and Pinion Elevators
32.14 Residential Elevators and Chair Lifts
32.15 Linear Elevator Motor Drive

MATERIAL HANDLING
32.16 General Information
32.17 Manual Load/Unload Dumbwaiters
32.18 Automated Dumbwaiters
32.19 Horizontal Conveyors
32.20 Selective Vertical Conveyors
32.21 Pneumatic Tubes
32.22 Pneumatic Trash and Linen Systems
32.23 Automated Container Delivery Systems
32.24 Automated Self-Propelled Vehicles
32.25 Summary

Key Concepts

- sky lobby (as an organizational and zoning approach)
- double-deck elevators (as a means of reducing shaft requirements)
- hydraulic elevator (as distinct from traction elevators)
- hole-less hydraulic elevator (as an alternative to conventional hydraulic systems)
- roped hydraulic elevator (as an alternative to conventional hydraulic systems)
- freight elevator (as a means of moving materials/goods)
- freight elevator load classifications (as a design consideration)
- observation cars and inclined elevators (as alternative elevator designs)
- linear elevator drive (as a potential new technology)
- residential elevators and chair lifts (as related to this scale of occupancy)
- material handling systems (as a requirement in many facilities)
- dumbwaiters, conveyors, pneumatic tube systems (as material handling options)
- automated container delivery (as a material handling option)
- self-propelled vehicles (as a material handling option)

Chapter 33: Moving Stairways and Walks

Summary: This chapter addresses moving stairways (escalators), moving walks, and moving ramps. Escalators are described as a means of carrying passengers quickly, comfortably, safely, and continuously. They can also be used to expose the rider to specific views. Escalators may be arranged in parallel (spiral or stacked) and crisscross (spiral or walkaround) layouts. Benefits, disadvantages, and design considerations related to these arrangements are discussed. Photos and sketches are provided to illustrate these installation options. Issues to consider when locating escalators are outlined. Escalator reversibility can provide system flexibility. Standard North American escalators are installed at a 30 degree angle, operate at 100 fpm, and are available in 32 inch and 48 inch sizes.

Escalator system components include a supporting truss, tracks, a sprocket assembly, the moving stairs themselves, handrail, balustrade, drive machine, and controls. The numerous safety features that are part of escalator operation are outlined. Four common means of providing fire protection at an escalator opening are described: the rolling shutter, smoke guard, spray-nozzle curtain, and sprinkler vent. Appropriate lighting is emphasized.

Application guidelines for escalator systems are given. Examples of installations and organizational arrangements are provided. The combined use of elevators and escalators as a people-moving strategy is discussed. Electric power requirements for escalators are reviewed. Non-standard escalator design options are introduced. Budget estimating is considered.

Moving walks and moving ramps are also presented. These somewhat similar systems are distinguished by their respective maximum slopes of 5 and 15 degrees. Typical applications for walks and ramps are reviewed. Size, capacity, and speed standards are presented.

Chapter Outline

MOVING ELECTRIC STAIRWAYS
33.1 General Information
33.2 Parallel and Crisscross Arrangements
(a) The crisscross arrangement
(b) Parallel escalators
33.3 Location
33.4 Size, Speed, Capacity, and Rise
33.5 Components
33.6 Safety Features
33.7 Fire Protection
33.8 Lighting
33.9 Application
33.10 Elevators and Escalators
33.11 Electric Power Requirements
33.12 Special-Design Escalators
33.13 Preliminary Design Data and Installation Drawings
33.14 Budget Estimating for Escalators

MOVING WALKS AND RAMPS
33.15 General Information
33.16 Application of Moving Walks
33.17 Application of Moving Ramps
33.18 Size, Capacity, and Speed
33.19 Components

Key Concepts

- escalator versus moving walk or ramp (as distinct systems for different situations)
- crisscross and parallel escalator arrangements (as an important design decision)
- design guidelines for escalator locations (as a design tool)
- standard escalator sizes (as basic design information)
- escalator system components (as necessary to an understanding of the system)
- operational and fire safety concerns (addressed by manufacturer and building designer)
- typical escalator applications (as a means of understanding system capabilities)
- elevator and escalator integration (as a design approach)
- standard escalator installation details (as a design tool)
- typical moving walk/ramp applications (as a means of understanding system capabilities)
- typical walk/ramp sizes (as a design tool)