BASICS OF RESIDENTIAL DESIGN

1

INTRODUCTION

Well-conceived and well-designed residential construction begins with an understanding of the basic concepts of site and space planning as well as of the natural forces that may impact the residence. Such considerations include function, technical performance, and aesthetics, which are all brought to bear on a final design. Successful designs are often a synthesis of these interrelated issues, and the solution is dependent upon the site, program, and budget.

This chapter discusses many of the basic planning and design concepts that are necessary for making good decisions. However, it is the designer's ability to apply design judgment to these concepts that results in good design solutions. The design guidelines presented here will assist the reader in applying good design judgment.

GENERAL GUIDELINES

Before design of a residential project begins, the designer must understand the needs and desires of the client, existing site conditions, regulatory requirements, the project's budget, environmental issues, and other factors that will influence the design and construction of the residence. Often the design process involves creation of an architectural program that defines the spaces and project requirements. The architectural program will assist in determining the square footage of the structure and the relationship of spaces.

The designer will perform an analysis of the site, identifying zoning restrictions, utility locations, topography, and other natural features. This will allow the designer to determine the buildable site area. The site analysis generally will also include review of the site context, including architectural styles, massing, environmental issues, and land uses of adjacent properties.

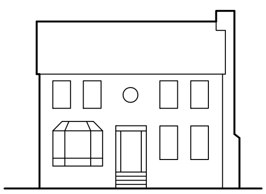
The final design is a synthesis of all the project considerations and technical requirements. The selection of building materials, structural systems, and design aesthetics are often driven by budgetary, context, and local considerations. The construction documents (Drawings and Specifications) convey the project requirements to the contractors.

IDENTITY FROM EXTERIOR

Image, often called "curb appeal," is frequently defined for the designer by the client. This is sometimes described as an architectural style or aesthetics. Considerations include materials, massing, and details.

Massing models are produced early in the design process to illustrate the general shape and mass of the residence. These models, whether physical, electronic, or three-dimensional drawings, show the house in relationship to other structures and physical objects, thus determining the context of the project. Historically, the more complex the massing, the more expensive will be the construction and more detail will be required in the construction documents.

MASSING TYPES
1.1



SIMPLE MASSING

COMPLEX MASSING

RESIDENTIAL PLANNING

Residences of all sizes have identifiable elements and sequences.

ENTRANCE

The entry of a home is the place where guests are greeted and first impressions are established. A dramatic spatial event at the moment of entry can establish the character of the interior of the house. The entry also is where the transition is made from exterior spaces to interior spaces. This event may require a transitional space, perhaps somewhat enclosed, as compression before expansion into the major semipublic areas of the house.

CIRCULATION AND ROOMS

In large houses, it is possible to separate circulation from the rooms served using devices such as corridors, passageways, foyers, vestibules, and the like. Circulation in smaller units occurs through rooms, most often living and dining rooms.

PLAN BALANCE

In residential design, the plan must be proportional and consistent. A multiple-bedroom dwelling with living areas too small to accommodate all the occupants is problematic. So is the house with enormous living and dining areas but too few or too small bedrooms. Kitchens, general storage, and circulation must also be sized according to the number of occupants.

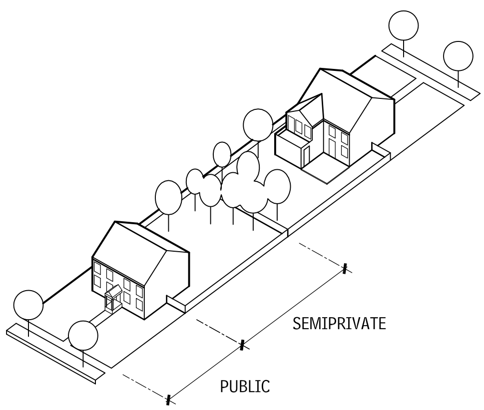
FOCUS

Dwellings often offer a hierarchy of experience culminating in a focus, which is commonly the living or living/dining area or family room/kitchen. This spatial focus is often enhanced by spatial definition and/or greater height, and by features such as fireplaces (the hearth, of course, is the traditional center of the house), stairs, or access to the outdoors.

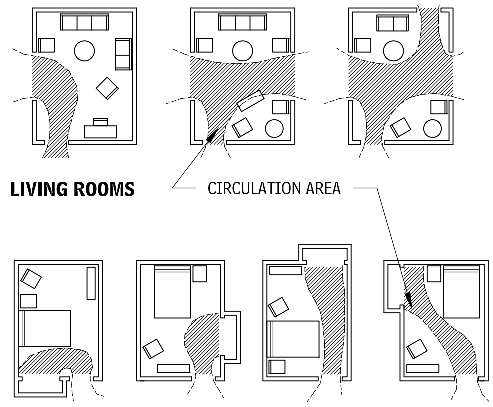
PLAN AND BUILDING MASSING

Plan arrangement is related to building massing; by projecting and recessing adjacent rooms or parts of rooms, building mass can be broken down. Similarly, continuous alignment of exterior walls leads to large-scale massing and elevations in which surface elements, such as windows and textured and colored surface areas, can be used to compose and adjust scale.

SIDEDNESS
1.2

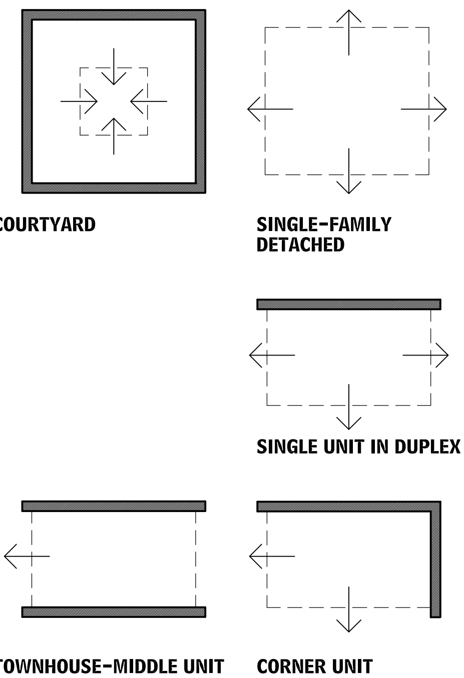


CIRCULATION AND ROOMS
1.3



BEDROOMS
IRC R304, R311

RESIDENTIAL DESIGN—POSSIBLE EXPOSURES
1.4



IRC R302, R303

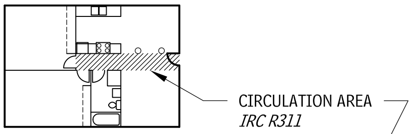
NOTES

1.2 Housing design usually distinguishes between public and semiprivate sides of the dwelling unit. Dwelling units usually benefit when buildings are designed with a clear front, or public, side, and a back, or semiprivate, side. Sidedness enables the cultivation of other contrasting characteristics such as ceremonial/intimate, open/closed, noisy/quiet, ornamented/plain, and urban/pastoral.

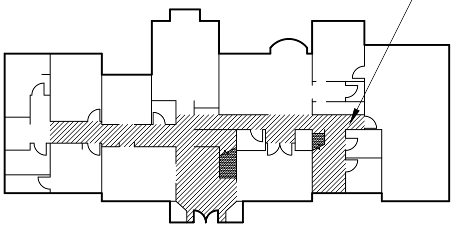
1.3 In small plans, circulation should occur through no more than two adjacent corners of any room. After accounting for circulation, sufficient space should remain for reasonable furniture arrangements.

1.4 The number of sides exposed to light and air and whether they are adjacent can be used to describe all dwelling units.

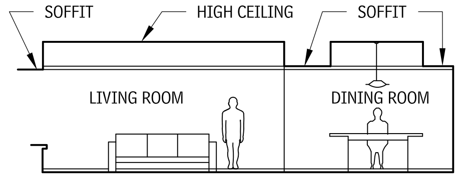
ARTICULATION OF SPACE
1.5



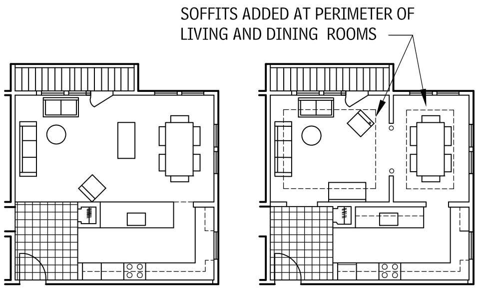
SMALL HOUSE



LARGE HOUSE



SECTION
IRC R305



BEFORE **AFTER SOFFITS ADDED**

PLANS

RESIDENTIAL PLANNING

PLANNING CONSIDERATIONS

DENSITY AND BUILDING TYPES

These factors are critical to the developed character of the site and are prescribed by zoning and by developer preference—as informed by the architect and others. Zoning density is typically expressed numerically as units per acre, along with limitations that are often intended to suggest unit type. Local zoning regulations may include setbacks, minimum lot size, floor area ratio, permitted land uses, and other restrictions. Subdivision and deed restrictions may also include development requirements that affect density and building type as well as accessory buildings.

UNITY AND VARIETY

In site design, monotony and excessive repetition are as undesirable as meaningless variation, which can be disorienting and appear chaotic.

EMERGENCY ACCESS

Size of emergency equipment, especially fire engines, can mandate street width, turning radius, and access patterns. Access to buildings becomes an issue at higher densities; installation of sprinkler systems can often balance equipment access around buildings. Always consult with the local fire official or planning department in the early stages of design.

SECURITY

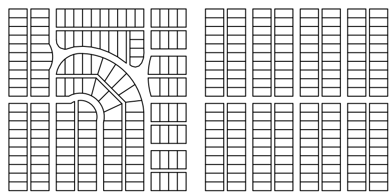
Because projects are sometimes produced and marketed as discrete places, security considerations can reinforce their hermetic character and prevent integration into the larger community. At higher densities, this phenomenon can produce gated communities with limited or single access, card-accessed parking areas, and private police.

Conventional urban patterns can sometimes replace costly and artificial surveillance systems: building placement, window location, and resident awareness, together with architectural limitations on free circulation, can enhance neighborhood security.

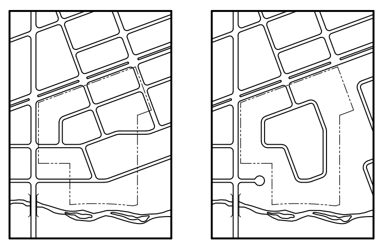
ACCESS

Although singular access is frequently desired for marketing and control, redundant access from existing automotive and pedestrian networks provides choice and convenience while reducing concentrations of traffic. Most fire departments and other authorities having jurisdiction require multiple access to ensure that subdivisions can be provided with adequate service by emergency vehicles.

ARBITRARY VARIATION AND MONOTONOUS REPETITION
1.6



MULTIPLE ACCESS AND SINGLE ACCESS
1.7



NOTE

1.5 Spaces defined by walls can be reinforced by articulation of the ceiling. Even in small units, ceiling drops and soffits can provide reinforcement of activity areas and spaces.

Contributor:
Ralph Bennett, Bennett Frank McCarthy Architects, Inc., Silver Spring, Maryland.

SINGLE-FAMILY DETACHED HOUSING

SITE PLAN CONSIDERATIONS

ACCESS

- Where possible, access should connect and align with existing infrastructure.
- Marketing and security considerations frequently dictate single access, but redundant circulation gives choice and improved service.
- Fire department requirements.

PEDESTRIAN CIRCULATION

- Rarely provided at lower densities, pedestrian access is essential at higher densities.
- Pedestrian walkways usually parallel streets.
- Connections to mass transit are appropriate and may be required by regulation.

PARKING

- Parking arrangements have a significant impact on density and appearance.
- On-street parking for guests is desirable at lower densities and essential at higher densities.

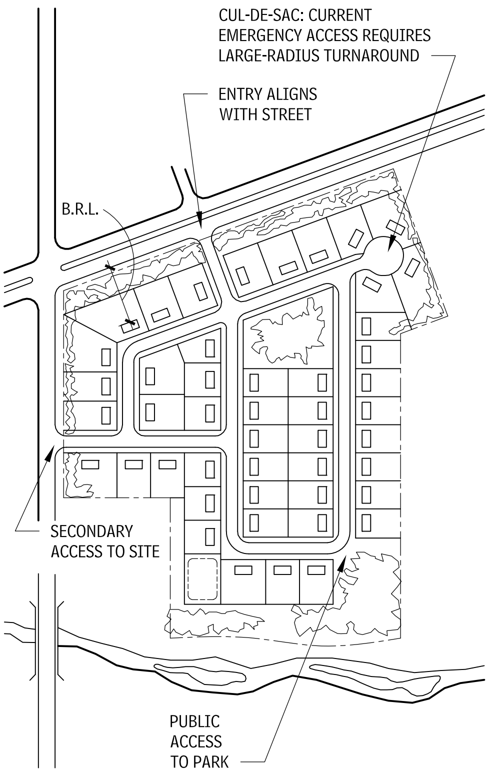
RELATION TO TOPOGRAPHY

- ADA and subdivision regulations dictate street and walk grades and mandate site reformation at all but the lowest densities.

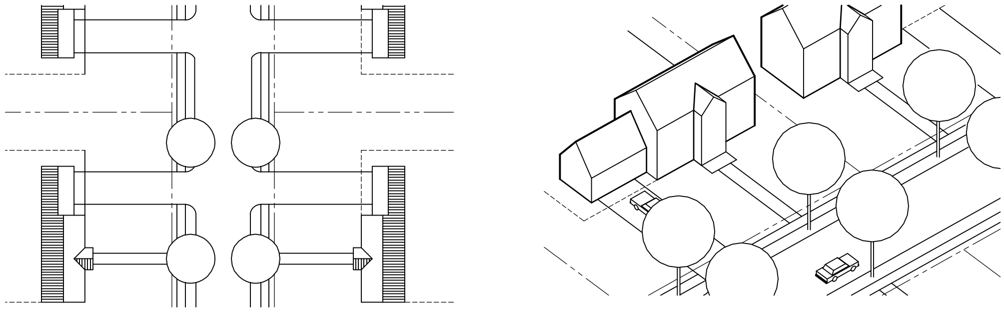
SERVICE

- Trash pickup, mail service, and deliveries depend on street access to individual units.
- Fire apparatus usually dictates road standards.

STREET ACCESS
1.8

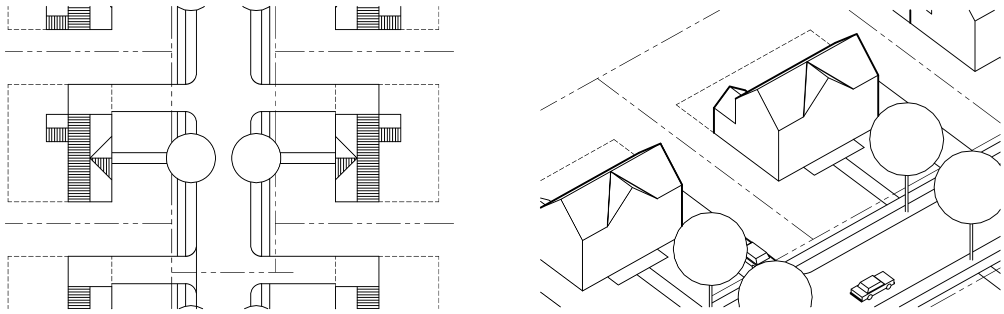


DENSITY CONFIGURATIONS
1.9



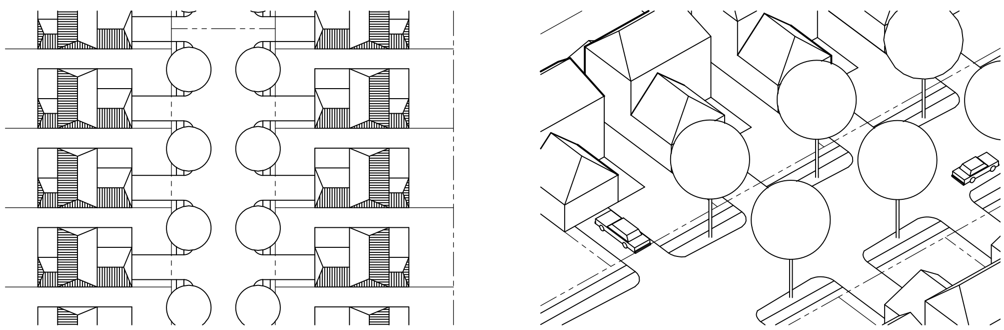
SHOWN AT 2 UNITS PER ACRE ON 100' x 200' LOTS

LARGE LOT SINGLE-FAMILY HOUSES



SHOWN AT 5 UNITS PER ACRE ON 75' x 100' LOTS

SMALL LOT SINGLE-FAMILY HOUSES



SHOWN AT 10 UNITS PER ACRE ON 40' x 90' LOTS

ZERO LOT SINGLE-FAMILY HOUSES
IRC R302.1

Contributor:
Ralph Bennett, Bennett Frank McCarthy Architects, Inc., Silver Spring, Maryland.

DETACHED HOUSING CHARACTERISTICS
1.10

TYPE	LOT SIZE (SQ FT)	DENSITY RANGE (D.U./ACRE)*	CHARACTERISTICS
Large lot	20,000 and up	0.5–5	Flexibility in orientation.
			Building restriction lines not significant.
			Expansion simple.
			Site character can be exploited.
Small lot	5,000–10,000	4–8	Aggregation becomes important.
			Community planning important.
			Services important (fire, mail, rubbish).
			Pedestrian circulation possible and required.
			Urban design principles apply.
			Building restriction lines become important.
			Public sewer and water needed.
			Clear delineation between public and private space needed.
Zero lot	3,000–5,000	8–11.5	Eliminates one sidelot setback.
			Shallower lots possible.
			Other side yard usable as private space.
			Windows on property line reduced or eliminated.
Z-lot	3,000–5,000	8–13	Similar to zero lot.
			Allows more flexible allocation of land.
			Lot line views over neighboring ownership must be avoided.
Alternating-width lots	3,000–5,000	8–11.5	Gives variety along street.

SINGLE-FAMILY ATTACHED HOUSING

SITE PLAN CONSIDERATIONS

ACCESS

- Where possible, should connect and align with existing infrastructure
- Many arrangements possible, including alleys, on-site parking, pooled parking, and on-street parking

PEDESTRIAN CIRCULATION

- Necessary to connect dwellings to common facilities and off-site facilities
- Usually parallel streets
- Lighting and safety issues

PARKING

- Has significant impact on density and appearance
- If not pooled, on-street essential for guests and overflow

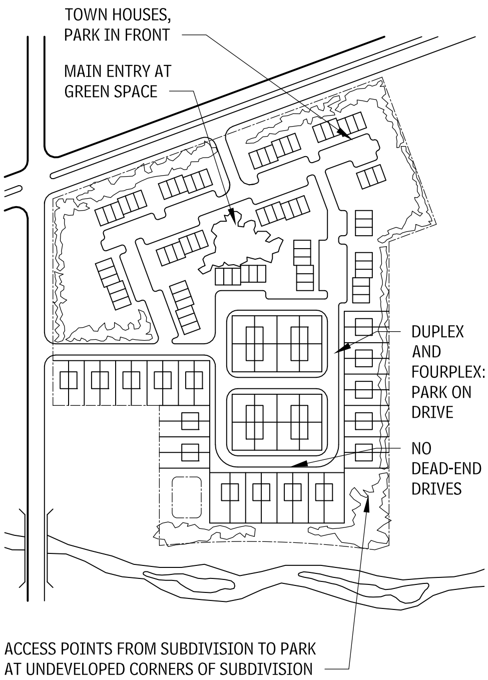
RELATION TO TOPOGRAPHY

- ADA, Fair Housing, and subdivision regulations dictate street and walk grades and mandate site reformation at all but the lowest densities.

SERVICE

- Trash pickup, mail service, and deliveries rely on access from street to individual units.
- Fire apparatus usually dictates road standards.

STREET ACCESS
1.11



NOTE

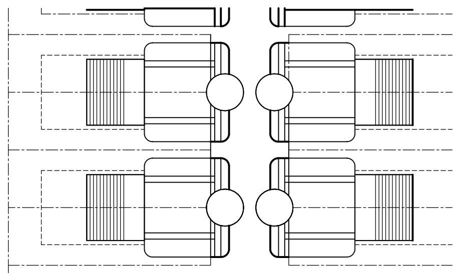
1.10 *D.U.— Dwelling Units.

Contributor:
Ralph Bennett, Bennett Frank McCarthy Architects, Inc., Silver Spring, Maryland.

MASSING

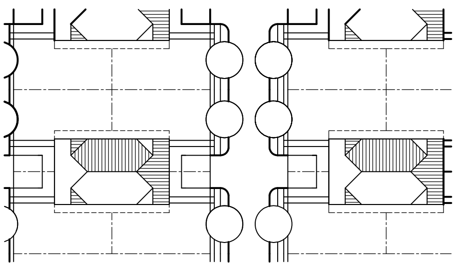
Variety and richness can be achieved by massing buildings so that individual units are not diagrammatically identifiable. Scale is given by secondary elements, room-size or smaller. Basic combinations are manipulated to produce complex unit configurations; the resulting composition is very different from basic types.

DENSITY CONFIGURATIONS
1.12



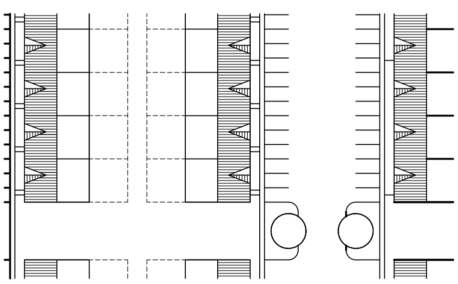
SHOWN AT 9 DWELLING UNITS PER ACRE

DUPLEX HOUSES



SHOWN AT 10 DWELLING UNITS PER ACRE

FOURPLEX HOUSES



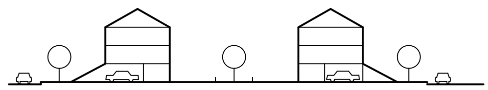
SHOWN AT 13 DWELLING UNITS PER ACRE

ATTACHED HOUSES (TOWN HOUSES)
IRC R302

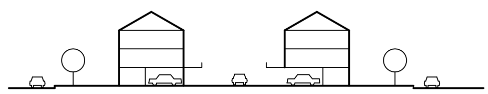
ATTACHED HOUSING CHARACTERISTICS
1.13

TYPE	LOT SIZE (SQ FT)	DENSITY RANGE (D.U./ACRE)*	CHARACTERISTICS
Duplex	3,000–5,000	8–10	Allows grouping of parking, access.
			Side yard can be used.
			Houses have three exposures.
Fourplex	2,000–3,000	10–15	Houses have two exposures.
			High level of privacy possible.
			Masses as larger building.
Townhouse	1,000–1,500	12–22	Urban type exported.
			Public/private clearly delineated.
			Maximum flexibility for minimum surface.
			Makes satisfactory streets.

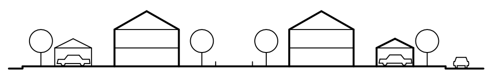
PARKING
1.14



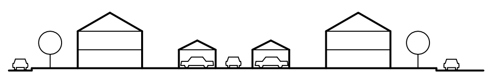
GARAGE UNDER HOUSE-FRONT ENTRY



GARAGE UNDER HOUSE-REAR ENTRY



GARAGE IN FRONT OF HOUSE



GARAGE BEHIND HOUSE
IRC R302.6

NOTES

1.13 *D.U. = Dwelling Units.
1.14 Attached houses achieve the highest density possible with individual structured parking (garages). Combining this housing type with parking produces many rich variations.

Contributor:
Ralph Bennett, Bennett Frank McCarthy Architects, Inc., Silver Spring, Maryland.

CRIME PREVENTION THROUGH ENVIRONMENTAL DESIGN

Security design and access control are more than bars on windows, a security guard booth, a camera, or a wall. Crime prevention involves the systematic integration of design, technology, and operation for the protection of three critical assets—people, information, and property. Protection of these assets is a concern and should be considered throughout the design and construction process.

The most efficient, least expensive way to provide security is during the design process. Designers who are called on to address security and crime concerns must be able to determine security requirements, must know security technology, and must understand the architectural implications of security needs.

The process of designing security into architecture is known as "crime prevention through environmental design" (CPTED). It involves designing the built environment to reduce the opportunity for, and fear of, stranger-to-stranger predatory crime. This approach to security design is different from traditional crime prevention practice, which focuses on denying access to a crime target with barrier techniques, such as locks, alarms, fences, and gates. CPTED takes advantage of opportunities for natural access control, surveillance, and territorial reinforcement. It is possible for natural and normal uses of the environment to meet the same security goals as physical and technical protection methods.

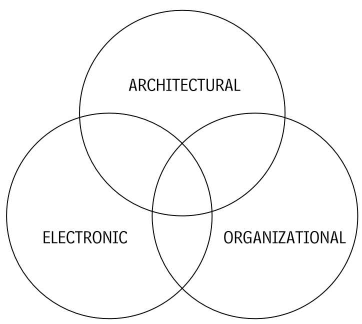
CPTED strategies are implemented by:

Electronic methods. Electronic access and intrusion detection, electronic surveillance, electronic detection, and alarm and electronic monitoring and control

Architectural methods. Architectural design and layout, site planning and landscaping, signage, and circulation control

Organizational methods. Manpower, police, security guards, and neighborhood watch programs

CPTED STRATEGIES
1.15



CPTED CONCEPTS

Concepts involved in crime prevention through environmental design are described below.

DEFENSIBLE SPACE

Oscar Newman coined the expression "defensible space" as a term for a range of mechanisms, real and symbolic barriers, strongly defined areas of influence, and improved opportunities for surveillance that combine to bring the environment under the control of its residents.

NATURAL ACCESS CONTROL

Natural access control involves decreasing opportunities for crime by denying access to crime targets and creating a perception of risk in offenders. It is accomplished by designing streets, sidewalks, entrances, and neighborhood gateways to mark public routes, and by using structural elements to discourage access to private areas.

NATURAL SURVEILLANCE

A design concept intended to make intruders easily observable, natural surveillance is promoted by features that maximize visibility of people, parking areas, and entrances. Examples are doors and windows that look onto streets and parking areas, pedestrian-friendly sidewalks and streets, front porches, and adequate nighttime lighting.

TERRITORIAL REINFORCEMENT

Physical design can create or extend a sphere of influence. In this setting, users develop a sense of territorial control, while potential offenders perceive this control and are discouraged from their criminal intentions. Territorial reinforcement is promoted by features that define property lines and distinguish private spaces from public spaces, such as landscape plantings, pavement design, gateway treatments, and fences.

MANAGEMENT AND MAINTENANCE

It is important to maintain neighborhoods and residences, and keep security components in good working order. Equipment and materials used in a dwelling should be designed or selected with safety and security in mind.

LEGITIMATE ACTIVITY SUPPORT

Legitimate activity for a space or dwelling is encouraged through the use of natural surveillance and lighting, and architectural design that clearly defines the purpose of the structure or space. Crime prevention and design strategies can discourage illegal activity and protect a property from chronic problem activity.

RESIDENTIAL STRATEGIES

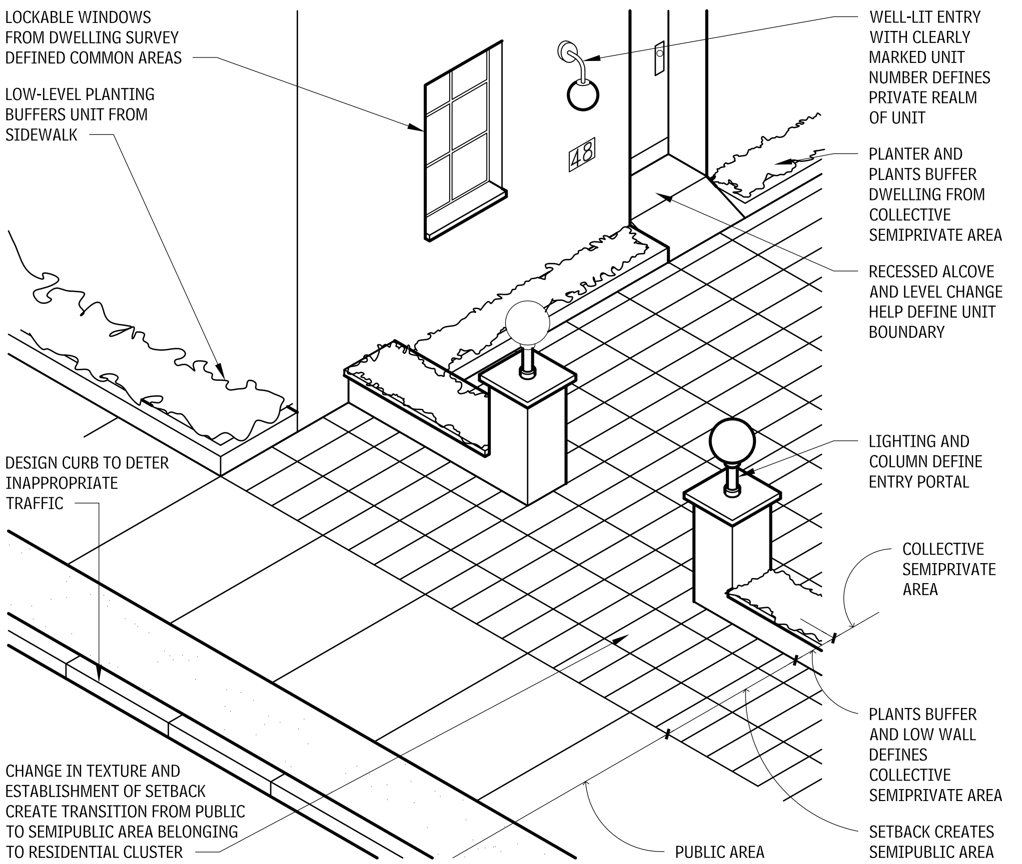
Designing CPTED and security features into residential buildings and neighborhoods can reduce opportunities for, and vulnerability to, criminal behavior and help create a sense of community. The goal in residential design is to create safe dwelling places through limited access to properties, good surveillance, and a sense of ownership and responsibility.

SINGLE-FAMILY DWELLINGS

NATURAL ACCESS CONTROL AND SURVEILLANCE

- Use walkways and landscaping to direct visitors to the proper entrance and away from private areas.
- All doorways that open to the outside as well as sidewalks and all areas of the yard should be well lit.
- Make the front door at least partially visible from the street and clearly visible from the driveway.
- Windows on all sides of the house should provide full views of the property. The driveway should be visible from the front or back door and from at least one window.
- Properly maintained landscaping should provide good views to and from the house.

SECURITY LAYERING OF SPACES
1.16



TERRITORIAL REINFORCEMENT

- Front porches or stoops create a transitional area between the street and the house.
- Define property lines and private areas with plantings, pavement treatments, or fences.
- The street address should be clearly visible from the street, with numbers a minimum of 5 in. high and made of nonreflective material.

SUBDIVISIONS

NATURAL ACCESS CONTROL

- Limit access to the subdivision without completely disconnecting it from neighboring areas. However, try to design streets to discourage cut-through traffic.
- Paving treatments, plantings, and architectural design features such as columned gateways can guide visitors away from private areas.
- Locate walkways where they can direct pedestrian traffic and remain unobscured.

NATURAL SURVEILLANCE

- Landscaping should not create blind spots or hiding places.
- Locate open green spaces and recreational areas so they can be observed from nearby houses.
- Use pedestrian-scale street lighting in areas with high pedestrian traffic.

TERRITORIAL REINFORCEMENT

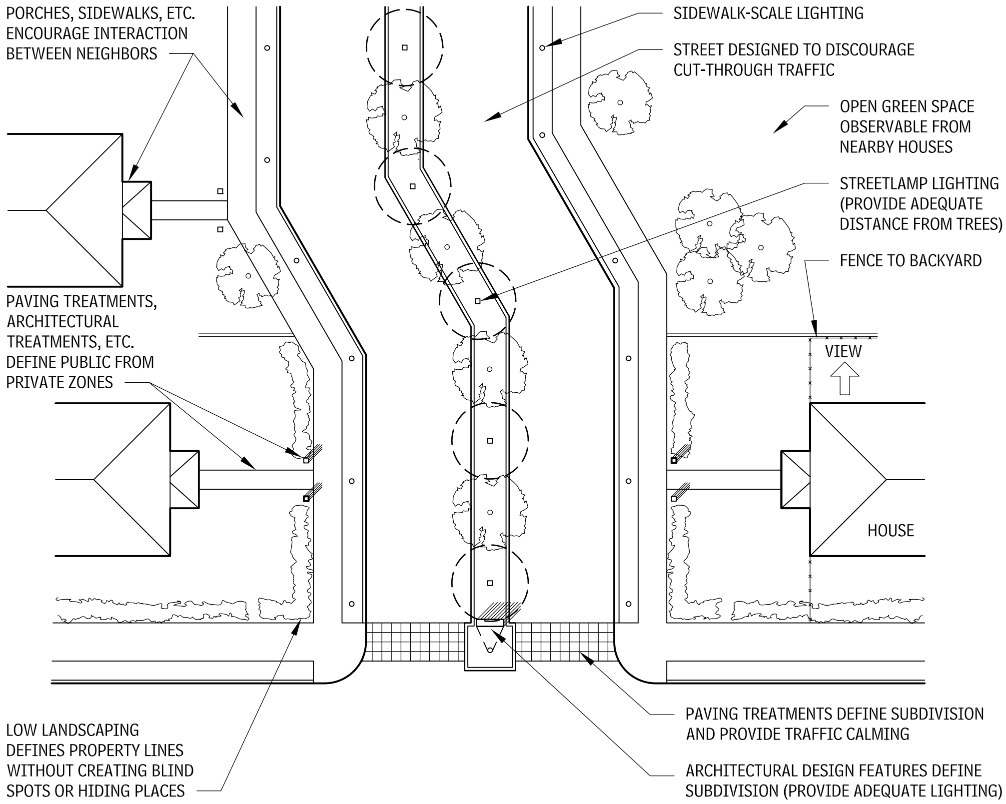
- Design lots, streets, and houses to encourage interaction between neighbors.
- Accent entrances with changes in street elevation, different paving materials, and other design features.
- Clearly identify residences with street address numbers that are a minimum of 5 in. high and well lit at night.
- Property lines should be defined with post-and-pillar fencing, gates, and plantings to direct pedestrian traffic.
- All parking should be assigned.

TWO-FAMILY DWELLINGS

NATURAL ACCESS CONTROL

- Balcony railings should never be made of a solid, opaque material or be more than 42 in. high.
- Define parking lot entrances with curbs, landscaping, and/or architectural design; block dead-end areas with a fence or gate.

CRIME PREVENTION THROUGH ENVIRONMENTAL DESIGN—PLANNING FOR SUBDIVISIONS
1.17



- Common building entrances should have locks that automatically lock when the door closes.
- Limit access to the building to no more than two points.

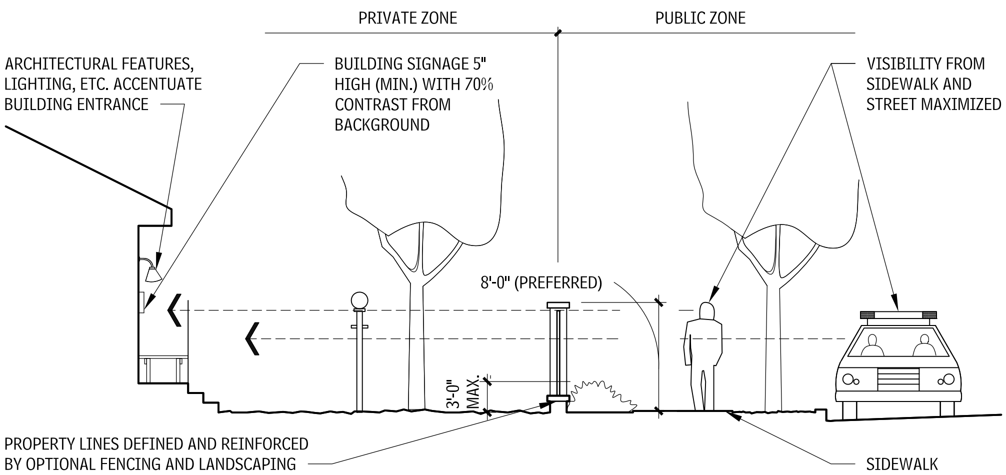
NATURAL SURVEILLANCE

- Make exterior doors visible to the street or neighbors, and ensure they are well lit.
- All four building facades should have windows. Site buildings so that the windows and doors of one unit are visible from those of other units.
- Assign parking spaces to each unit and locate them next to the unit. Designate special parking spaces for visitors.
- Parking areas and walkways should be well lit.
- Recreation areas should be visible from a multitude of windows and doors.
- Dumpsters should not create blind spots or hiding places.
- Shrubbery should be no more than 3 ft high for clear visibility and tree canopies not lower than 8 ft 6 in.

TERRITORIAL REINFORCEMENT

- Define property lines with landscaping or post-and-pillar fencing, but keep shrubbery and fences low to allow visibility from the street.
- Accent building entrances with architectural elements and lighting and/or landscape features.
- Doorknobs should be 40 in. from window panes.
- Clearly identify all buildings and residential units with well-lit address numbers a minimum of 5 in. high.
- Common doorways should have windows and be key-controlled by residents.
- Locate mailboxes next to the appropriate residences.

CRIME PREVENTION THROUGH ENVIRONMENTAL DESIGN—PLANNING FOR RESIDENTIAL PROPERTY
1.18

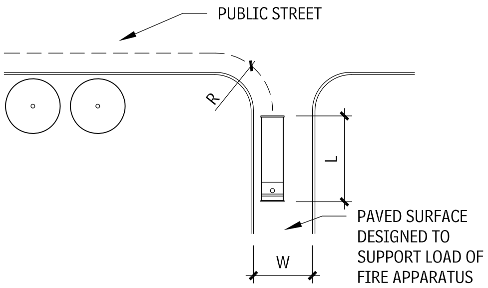


Contributor:
Randall I. Atlas, Ph.D., AIA, CPP, Atlas Safety & Security Design, Inc., Miami, Florida.

SITE PLANNING FOR FIRE PROTECTION

FIRE APPARATUS ACCESS

FIRE APPARATUS ACCESS
1.19



Fire apparatus (i.e., pumpers, ladder trucks, tankers) should have unobstructed access to buildings. Check with the local fire department for apparatus turning radius (R), length (L), and other operating characteristics. Support systems embedded in lawn areas adjacent to the building are acceptable.

RESTRICTED AREAS

Buildings constructed near cliffs or steep slopes should not restrict access by fire apparatus to only one side of the building. Grades greater than 10% make operation of fire apparatus difficult and dangerous. Avoid parking decks abutted to buildings. Consider pedestrian bridge overs instead.

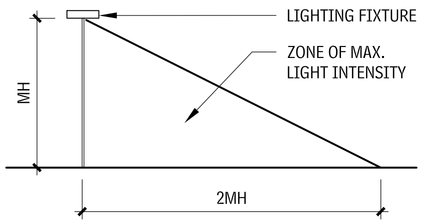
FIRE DEPARTMENT RESPONSE TIME FACTOR

Site planning factors that determine response time are street accessibility (curbs, radii, bollards, T-turns, culs-de-sac, street and site slopes, street furniture and architectural obstructions, driveway widths), accessibility for firefighting (fire hydrant and standpipe connection layouts, outdoor lighting, identifying signs), and location (city, town, village, farm). Check with local codes, fire codes, and fire department for area regulations.

OUTDOOR LIGHTING

Streets that are properly lit enable firefighters to locate hydrants quickly and to position apparatus at night. Avoid layouts that place hydrants and standpipe connections in shadows. In some situations, lighting fixtures can be integrated into building exteriors. All buildings should have a street address number on or near the main entrance.

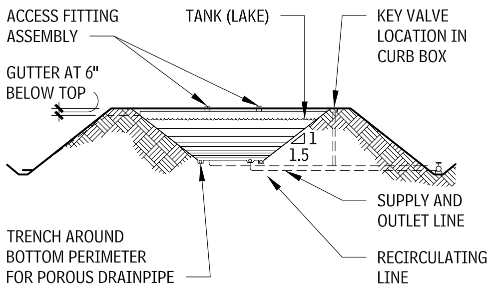
OUTDOOR LIGHTING
1.20



ON-SITE LAKES

Man-made and natural on-site lakes may be used for firefighting in suburbs, on farms, and at resorts. A dry hydrant is piped from the lake. Man-made lakes with reservoir liners can be berm supported or sunk in the ground. Lakes and ponds are natural water supplies that are dependent upon the environment. See local codes, fire codes, and fire departments for on-site lake regulations.

ON-SITE LAKE
1.21



CONTROL OF FLOOD DAMAGE

FLOOD DAMAGE MANAGEMENT

Flood hazards are caused by building in flood-prone areas. Floods cannot be prevented, but the damage they wreak on man-made properties can be managed, either by altering the flood potential of an area or by avoiding construction in locations subject to flooding. Historically, flood damage management in the United States has focused on the former management technique, attempting to divert floods with structural flood controls—dams, levees, and channel modifications. However, such flood control measures have proved unsatisfactory over time.

Structural flood control projects have tended to encourage development in high-hazard areas, often without appropriate land use planning. When a storm exceeds or violates the design parameters of a flood control structure, the damage that results from a flood can exceed what would have occurred if the structure had not been built. For example, floodplain invasion often occurs where levees have been built with the intention of reducing damage to agriculture. Although in some regions, levees have reduced the number of high-frequency floods, in general, they cause conditions favorable for their own failure by altering erosion patterns and increasing flood stages.

Recognition of the cost of development in high-risk areas, the uneven distribution of flood hazards on the landscape, and the natural and beneficial values of floodplains have led to more common adoption of nonstructural flood hazard management techniques. In particular, land use management and modified building practices are finding widespread acceptance.

Information on flood damage management and floodplain and wetland conservation is available from the Federal Emergency Management Agency (FEMA), the Natural Hazards Research Applications and Information Center, the U.S. Army Corps of Engineers, the Environmental Protection Agency (EPA), the National Park Service, and state and local agencies.

FLOOD HAZARDS

Most flood damage is caused by such weather conditions as hurricanes, fronts associated with midlatitude cyclones, thunderstorms, and melting snowpacks. These conditions interact with surface features, such as floodplains, coasts, wetlands, and alluvial fans, resulting in floods, mudslides, and erosion. Geologic phenomena such as earthquakes may also trigger floods.

Weather and climate information is available from the National Climate Data Center, regional climate research centers, and state climatology offices. Geologic and hydrologic information is available from the U.S. Geological Survey and state geological and geographical surveys.

FLOOD-PRONE AREAS

Floodplain. The relatively flat area within which a river moves and upon which it regularly overflows.

Rivers typically meander over their floodplains, eroding the cutbank and redepositing sediments in accretion zones, such as point bars, meander belts, and natural levees. Channel shifting may be extreme in alluvial fans. Coastal floodplains, which include barrier islands, shores, and wetlands, have the same relationship to the sea that riverine floodplains have to rivers.

Wetlands. Areas characterized by frequent flooding or soil saturation, hydrophytic vegetation (vegetation adapted to survival in saturated areas), and hydric soils (soil whose chemical composition reflects saturation). Wetlands are often found in floodplains but are more restrictively defined.

FLOOD TYPES

Floods may be classified by their locations or physical characteristics.

Riverine flood. Great overflows of water from a river channel onto a floodplain, caused by precipitation over large areas, melting snow, or both. Overbank flow is a normal geophysical event that occurs on average every two years for most rivers.

Headwater flood. A riverine flood that results from precipitation directly in a basin.

Backwater flood. A riverine flood caused by high stages on downstream outlets, which prevent drainage from tributary basins or even reverse the flow.

Coastal flood. Overflows onto coastal lands bordering an ocean, estuary, or lake. Coastal floods are caused by tsunamis (seismic sea waves), hurricanes, and northeasters.

Flash flood. A local flood of great volume and short duration. Flash floods differ from riverine floods in extent and duration. Flash floods generally result from a torrential rain or "cloudburst" covering a relatively small drainage area. Flash floods may also result from the failure of a dam or sudden breakup of an ice jam.

FLOOD RISKS

Flood risk is usually expressed as the estimated annual frequency with which a flood equals or exceeds a specified magnitude. The flood risk for a future period of time is the joint probability of the occurrence of the annual flood risk. For example, if a house is situated at the "100-year flood" elevation (1% annual exceedance frequency), then its flood risk for a 30-year period is 26%, or approximately a one-in-four chance it will be flooded to the specified depth or greater.

Standard projected flood (SPF). A flood that may be expected from the most severe combination of meteorological and hydrological conditions characteristic of the geographic area in which the drainage basin is located, excluding extremely rare combinations.

SPFs are used in designing dams and other facilities with high damage potential.

Probable maximum flood (PMF). The most severe flood that may be expected from a combination of the most critical meteorological and hydrological conditions reasonably possible in a drainage basin. (This term is not a statistical concept.)

PMFs are used in designing high-risk flood protection works and in siting structures and facilities that must be subject to almost no risk of flooding.

LAND USE IN FLOOD ZONES

Land use management is the most effective method of managing flood damage. State control of land use in hazardous areas, authorized by the police-powers clause of the U.S. Constitution, is usually delegated to local planning and zoning boards. Local, state, and federal governments also regulate ecosystems essential for flood damage management, such as wetlands, coastal dunes, and mangrove stands. Land use management often includes setback regulations, which attempt to limit flood-related erosion damage. Regardless of regulations imposed by the government, developers should evaluate building sites for their intrinsic suitability for the intended use.

The National Flood Insurance Program (NFIP) requires that participating local governments adopt minimum floodplain management plans based on data provided by the federal insurance administrator. The NFIP does not require local governments to adopt land use or transportation plans that require preferential development of hazard-free areas or prohibit development of land in high-hazard areas. New construction in coastal zones is required to be located landward of the reach of the mean high tide. Local land use and development or floodplain management plans that are more stringent than NFIP requirements supersede NFIP requirements. The NFIP divides riverine floodplains into floodway and floodway fringes for land use management. Coastal floodplains are divided into coastal high-hazard areas and coastal fringes. Land uses in these areas should always be verified with local agencies.

FLOODWAYS

Floodways include the channel of a watercourse and those portions of the adjoining floodplain required to permit the passage of a flood of specified magnitude at no more than a specified level above natural conditions. The NFIP requires floodways to be large enough to accommodate floods with a 1% annual exceedance frequency (100-year flood) without causing an increase in water levels of more than a specified amount (1 ft in most areas). Some localities object to the acceptability of increased flood levels this NFIP requirement implies. Instead, they define the floodway as the area inundated by floods with a 4% annual exceedance frequency (25-year flood).

Uses permitted in a floodway are those with low flood damage potential that do not obstruct flood flows or require structures, fill, or storage of materials or equipment. Fill is prohibited, and most structures are strongly discouraged. The following uses are generally permitted:

Functionally dependent uses. Facilities and structures that must be located close to water in order to function, such as docking and port facilities and shipbuilding and repair facilities. Water supply and sanitary sewage treatment plants must be flood-proofed if they must be located adjacent to bodies of water.

Agricultural uses. General farming, pasture, outdoor plant nurseries, horticulture, viticulture, truck farming, forestry, sod farming, and wild crop harvesting.

Recreational uses. Golf courses, tennis courts, driving ranges, archery ranges, picnic grounds, boat launching ramps, swimming areas, parks, wildlife and nature preserves, game farms, fish hatcheries, shooting preserves, target ranges, trap and skeet ranges, hunting and fishing areas, and hiking and horseback riding trails.

Incidental industrial-commercial uses. Loading areas, parking areas, and airport landing strips (except in flash flood areas).

Incidental residential uses. Lawns, gardens, parking areas, and play areas.

FLOODWAY FRINGES

Floodway fringes are the portion of the regulatory floodplain outside of the floodway. Floodway fringes are treated as storage areas for flood waters. Where permitted, property owners on each side of the floodplain may obstruct flood flows equally.

Uses permitted in floodway fringes include those permitted in floodways and elevated or otherwise flood-proofed structures. Prohibited or strongly discouraged uses include facilities for storing materials that are toxic or flammable or explosive in water, vital facilities such as hospitals and civil defense or rescue facilities, and facilities that are difficult to evacuate, such as nursing homes and prisons.

FLOOD INSURANCE RATE ZONES

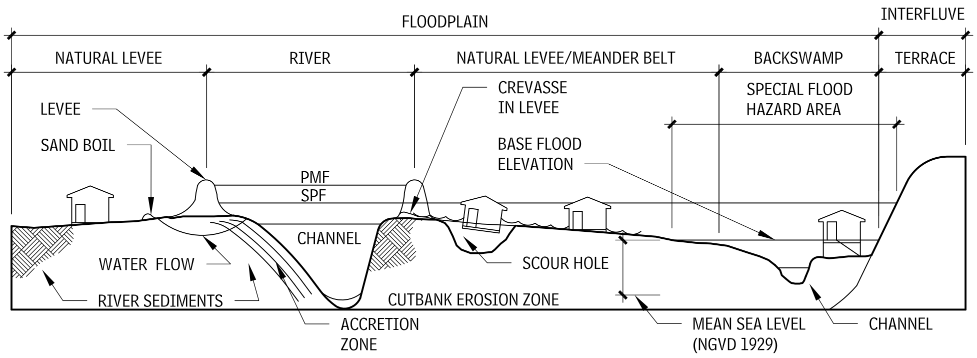
The NFIP is a program intended to reduce federal expenditures for flood disaster relief. It provides flood damage insurance as an incentive for communities to adopt floodplain management regulations, especially those governing floodplain obstructions and building practices in floodplains. NFIP minimum standards require a low level of flood damage management based on historic conditions.

States and localities may establish standards higher than NFIP's, in which case, these supersede NFIP standards. For example, other governments may control land use in hazardous areas, regulate runoff, or have freeboard requirements; they may also base regulatory flood elevations on historic floods that exceeded the base flood, or on the projected effects of future development. The NFIP Community Rating System provides insurance rate reductions as an incentive to adopt higher standards.

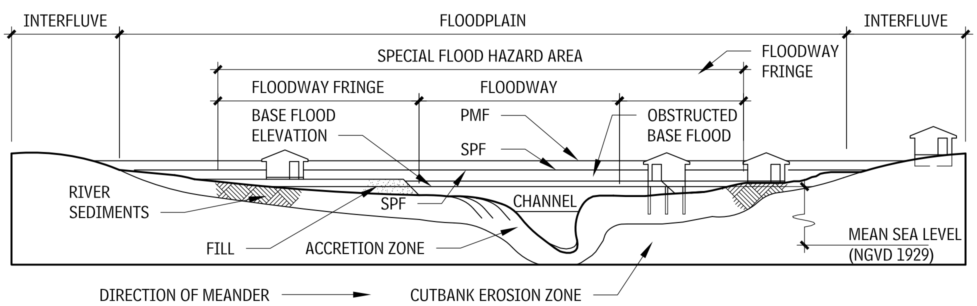
The NFIP bases Flood Insurance Rate Zones on the frequency of flooding and the presence of storm surge and waves. Local governments are typically required to regulate building practices in A and V zones as a condition of eligibility for flood insurance.

The most important requirement in A and V zones is that the first floor of new buildings be built equal to or higher than the base flood level, which has a 1% chance of being equaled or exceeded in any given year (100-year flood). The base flood is the still-water height for riverine floods. For the Atlantic Coast and the Gulf of Mexico, the base flood includes storm surge plus wave crest height because of northeasters and hurricanes. The base flood for the Pacific Coast includes astronomical tides plus wave run-up caused by tropical cyclones and tsunamis. For major lakes, the base flood includes seiche (sloshing because of wind, seismic activity, and storm surge). The base flood elevation (BFE) is the height of the base flood in reference to mean sea level as defined by the National Geodetic Vertical Datum of 1929 (NGVD 1929).

INVERTED RIVER VALLEY AND V-SHAPED RIVER VALLEY
1.22



INVERTED RIVER VALLEY



V-SHAPED RIVER VALLEY

Contributor:
Mattie Fincher Coxe, Baton Rouge, Louisiana.

Local communities may adopt regulatory flood datums (RFD) in place of base flood elevations. RFDs are the base flood plus a freeboard: a factor of safety expressed in feet and used to compensate for uncertainties that could contribute to greater flood height than that computed for a base flood. Freeboard allows for hazards excluded from consideration in figuring the base flood and uncertainties in analysis, design, and construction. Severe structural subsidence, increases in floods because of obstructions in the floodplain, urban runoff, or normal climatic variability, as well as long-term increases in sea level and storms, are often excluded from consideration in determining base flood levels. Urban conditions, low accuracy base maps, and unplanned development are other common sources of uncertainty that justify freeboard.

Some communities require up to a 3-ft freeboard to compensate for inaccurate flood insurance rate maps (FIRMs). The margin of error of base maps may be estimated as plus or minus one-half of the contour interval. Most FIRMs are developed from maps with a contour interval of 5 ft, and a margin of error of −2-1/2 ft. Field survey maps with a contour interval of 2 ft or less are used in some communities; the smaller interval reduces the uncertainty of the risk and the need for freeboard.

The NFIP classifies land as either special flood hazard areas (SFHAs)—high-frequency flood, flood-related erosion, and mudslide zones—or low-risk and undetermined flood hazard zones. Zone names that include actuarial risk factors, such as A1–A30 and V1–V30, are being replaced by AE and VE designations with flood depths.

A ZONES (A, AE, A1–A30, AO, AH, AR, A99)

Zones A and AE (formerly A1–A30) are high-risk riverine areas susceptible to inundation by the still-water base flood. AO zones are areas of shallow flooding (1 to 3 ft) without defined channels, usually sheet flow on sloping terrain. AH zones indicate shallow flooding, usually with water ponding. AR zones are areas in which structural flood protection is deficient. A99 zones are areas in which structural flood protection systems are near completion.

The finished floor of the lowest habitable level of residences, usually including basements, must be elevated to the base flood elevation in zone A. Flood-resistant residential basements are permitted only in communities that meet special NFIP flood criteria and adopt special local standards for their design and construction. Commercial structures must be elevated or otherwise floodproofed to the BFE.

B ZONES

B zones indicate areas subject to inundation by floods with an annual exceedance frequency greater than the base flood with less than a 0.2% annual exceedance frequency (500-year flood). B-zone designations are not used on recent FIRMs because of the lack of statistical validity of most estimates of 500-year floods and the false perception that they are generally safe. On some maps, B zones are shown as shaded X zones.

C ZONES

C zones, including all areas that are not in zones A, B, or V, are not necessarily flood free. They may include low-risk interfluvial regions (areas of a watershed above the natural floodplain), moderate-risk floodplains between the interfluve and the regulatory floodplain, areas with localized nonriverine flooding, high-risk areas with small contributing drainage areas, and floodplains with structural flood protection that may be subject to low-frequency catastrophic floods.

D ZONES

D zones are areas of possible but undetermined flood hazard.

X ZONES

X zones include all areas not in zones A or V, combining B and C zones found on older maps. On some maps, X zones that were formerly B zones, and X zones within levee systems are shaded.

V ZONES (V, VE, V1–V30, VO)

Velocity zones V and VE (formerly V1–V30) are coastal high-hazard areas identified as susceptible to inundation by the base flood, including storm surges with high-velocity waves greater than 3 ft. Generally, zone V indicates the inland extent of a 3-ft breaking wave, where the still-water depth during the 100-year flood decreases to less than 4 ft. VO zones are proposed alluvial fan zones with high-velocity shallow flow (1 to 3 ft) and unpredictable flow paths.

Elevation and structural requirements are most stringent in coastal high-hazard areas. Fill below buildings is prohibited. If construction is permitted by the local government, the lowest horizontal structural member of the lowest habitable floor must be built above the base flood elevation. Rigid frames or semirigid frames with grade beams can resist the impact of storm surge and waves. Semirigid frames without grade beams should be used only in areas not subject to potential scour. Freestanding pole structures are unsafe; large rotations develop at moment connections, causing deflection of pilings under sustained lateral loads that can lead to collapse.

Destruction of coastal dunes and wetlands dramatically increases the inland reach of storm surge and waves and increases the severity of flood damage. Buildings may be destroyed if dunes and wetlands are inadequately protected, even if they conform to legal building requirements.

E AND M ZONES (E, M)

E zones are areas adjoining the shores of a lake or other bodies of water that are likely to suffer flood-related erosion. M zones are areas with land surfaces and slopes of unconsolidated material in which the history, geology, and climate indicate a potential for mudflow. Setbacks and special building requirements are used in E and M zones. Refer to the following references for additional information.

Coastal Construction Manual (FEMA-55), Third Edition. Dames & Moore and Bliss & Nyitray, Inc., 2000.

Elevating to the Wave Crest Level: A Benefit-Cost Analysis (FIA-6), Shaeffer & Roland, Inc., 1988.

Federal Emergency Management Agency. Answers to Questions About the National Flood Insurance Program (FIA-2). Washington, DC: FEMA, 1997.

Federal Emergency Management Agency. The Floodway: A Guide for Community Permit Officials. Community Assistance Series No. 4. Washington, DC: FEMA.

Flood Loss Reduction Associates. Floodplain Management Handbook. U.S. Water Resources Council, 1981.

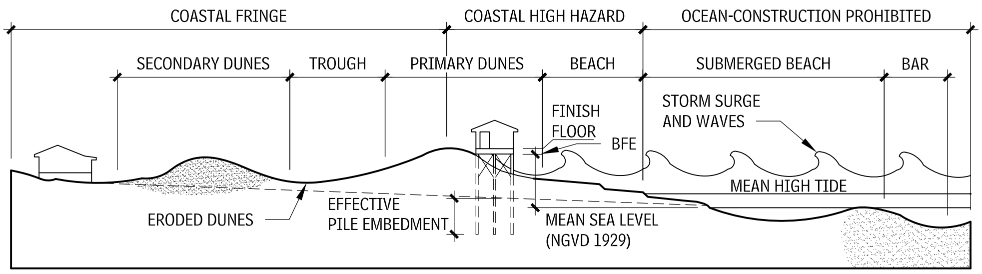
Floodproofing Nonresidential Structures (FEMA-102). Booker Associates, Inc., 1986.

Hayes, W. W., ed. Facing Geologic and Hydrologic Hazards: Earth-Science Considerations. Washington, DC: U.S. Geological Survey, 1981.

GENERAL LIMITS OF FLOODPROOFING
1.23

METHOD	DEPTH	VELOCITY	WARNING REQUIREMENTS
Levees of floodgates in openings	4′–7′	< 10′/sec	Advance warning required for installation.
Floodwalls	4′–7′	< 12′/sec	
Closures (24 hr maximum)	4′–8′	< 8′/sec	5–8 hr advance warning required for installation of closures.
Fill	10′+	< 10′/sec	Evacuation time required unless fill connects to higher ground.
Piles, piers, and columns	10′–12′	< 8′/sec	Adequate evacuation time required.

COASTAL DUNES AND BEACHES
1.24



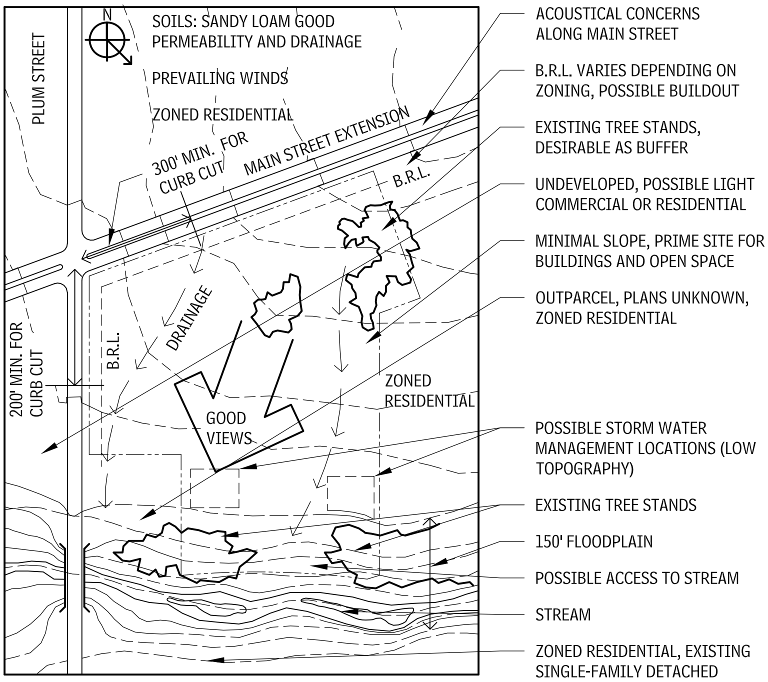
NOTE

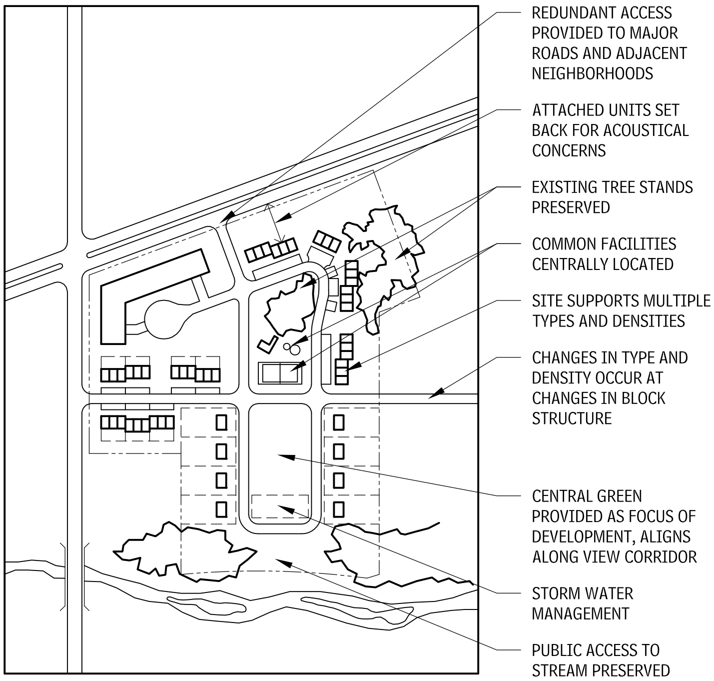
1.23 Information presented is general and warrants caution. Time available for warning may be severely limited by a flood's rate of rise.

Contributor:
Mattie Ann Fincher, Baton Rouge, Louisiana.

RESIDENTIAL SITE PLANNING

SITE ANALYSIS AND SCHEMATIC SITE PLAN
1.25





GENERAL GUIDELINES

Residential site planning requires balance among a large number of complex and often competing priorities.

ORIENTATION

No unit should be without sun for at least part of a winter day; south-facing units are premium. Prevailing winds, both regional and local, should be studied so that no building is entirely masked. At the same time, harsh winds should be buffered by plantings, and if buildings are differentiated by side, bedroom and service sides should face the harsh wind.

USE AND ENHANCEMENT OF NATURAL AMENITIES

Too frequently, housing projects are named for amenities that are destroyed during development. Promontories, mature trees, and water features should be incorporated into the design and, if possible, enhanced.

PROVISION FOR VIEWS

Spectacular views can drive the design of a housing project, but every project should strive to provide reasonable views from all units. Although no unit should have a parking area as its only view, many people enjoy views of streets and roadways. Views of green spaces are important, especially in urban projects.

CONTEXT

The designer must strive to identify valuable off-site resources and influences so that they are recognized in the design.

Such resources include the following:

- Geometries and alignments
- Slopes and soils
- Views of singular objects and natural amenities
- Recreational facilities
- Topography and drainage
- Surrounding and adjoining uses
- Available infrastructure
- Market and location

CLEAR DELINEATION OF PRIVATE AND PUBLIC AREAS

Beyond unit design considerations, the site should be organized so that all territory can be clearly allocated to either private custody or public care and maintenance. It is frequently desirable for each unit to control some private open space. However, in higher-density developments, such space is often limited or filled in unique ways.

REGULATORY REQUIREMENTS

Land available for housing and related uses may face restrictions, including the following:

- Rights-of-way for future uses
- Area required for storm water management and sediment control
- Mandated unusable areas between projects (called "buffers")
- Building restriction lines: setbacks, build-to lines, height limits, viewsheds, watersheds, separations, right-of-way, easements
- Roadways and parking areas
- Protection of environmentally sensitive and natural resource areas such as forests, streams, and animal habitats

SOLAR RADIATION AND BUILDING ORIENTATION

OPTIMUM ORIENTATION

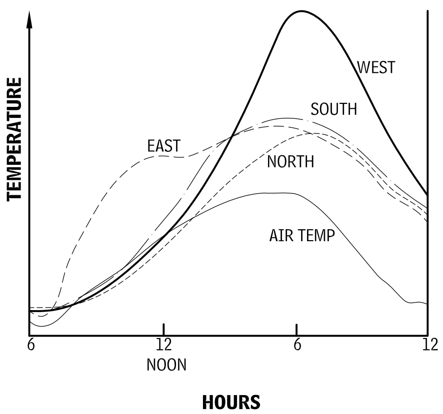
To visualize the thermal impacts on differently exposed surfaces, four sites are shown in Figure 1.27 at approximately the 24°, 32°, 40°, and 44° latitudes. The forces are indicated on average clear winter and summer days. The air temperature variation is indicated by the outside concentric circles. Each additional line represents a 2° difference from the lowest daily temperature. The direction of the impact is indicated according to the sun's direction as temperatures occur. (Note the low temperatures at the east side, and the high ones in westerly directions.)

The total (direct and diffuse) radiation impact on the various sides of the building is indicated with arrows. Each arrow represents 250 Btu/sq ft/day radiation. The radiations are expressed in numerical values in Table 1.28.

The values show that in the upper latitudes, the south side of a building receives nearly twice as much radiation in winter as in summer. This effect is even more pronounced at the lower latitudes, where the ratio is about one to four. Also, in the upper latitudes, the east and west sides receive two to three times as much radiation as the south elevation. In the summer, the west exposure is more disadvantageous than the east exposure, as the afternoon high temperatures combine with the radiation effects. In all latitudes, the north side receives only a small amount of radiation, and in the summer, the north side receives nearly twice the impact of the south side. The amount of radiation received on a horizontal roof surface exceeds all other sides.

Experimental observations were conducted on the thermal behaviors of building orientation at Princeton University's Architectural Laboratory. Figure 1.26 shows the summer results of structures exposed to the cardinal directions. Note the unequal heat distribution and high heat impact of the west exposure compared to the east orientation. The southern direction gives a pleasantly low heat volume, though it is slightly higher than the north exposure.

ROOM TEMPERATURES IN DIFFERENTLY ORIENTED HOUSES
1.26



We can conclude:

- The optimum orientation will lie near the south; however, it will differ in the various regions and will depend on the daily temperature distribution.
- In all regions, an orientation eastward from south gives a better yearly performance and a more equal daily heat distribution. Westerly directions perform more poorly with unbalanced heat impacts.
- The thermal orientation exposure has to be correlated with the local wind directions.

TOTAL DIRECT AND DIFFUSED RADIATION (BTU/SQ FT/DAY)
1.28

LATITUDE	SEASON	EAST	SOUTH	WEST	NORTH	HORIZONTAL
44° LATITUDE	WINTER	416	1,374	416	83	654
	SUMMER	1,314	979	1,314	432	2,536
40° LATITUDE	WINTER	517	1,489	517	119	787
	SUMMER	1,277	839	1,277	430	2,619
32° LATITUDE	WINTER	620	1,606	620	140	954
	SUMMER	1,207	563	1,207	452	2,596
24° LATITUDE	WINTER	734	1,620	734	152	1,414
	SUMMER	1,193	344	1,193	616	2,568

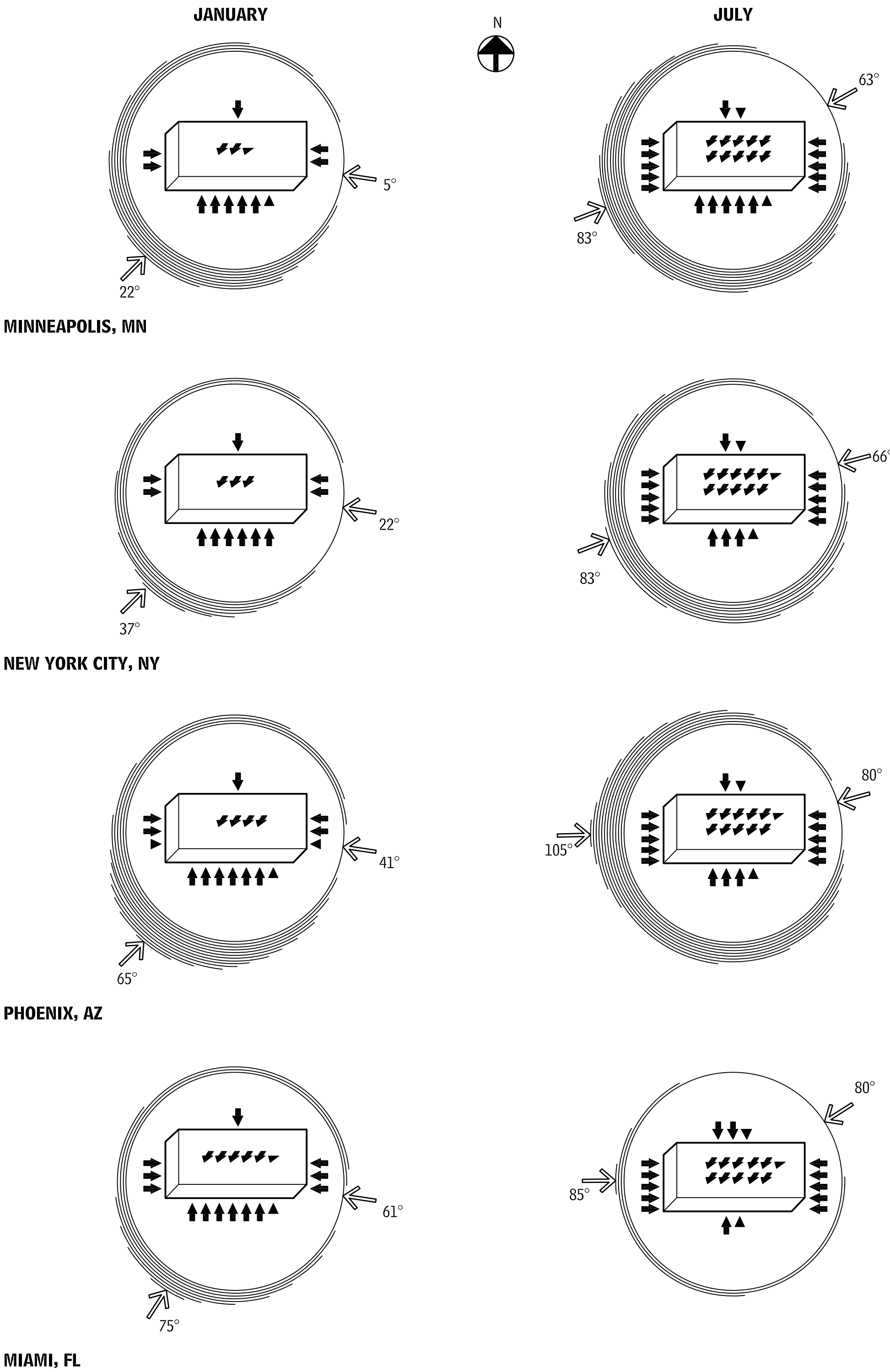
SOLAR CONSTANT, SOLAR ANGLES, AND SHADOW CONSTRUCTION

SOLAR CONSTANT

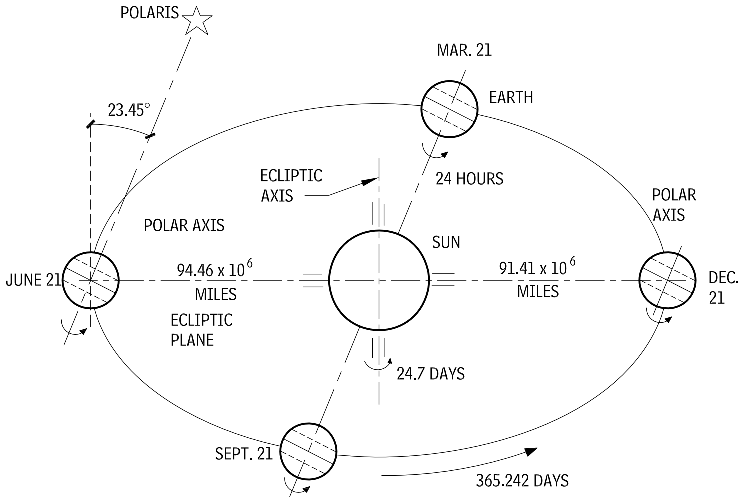
The sun is located at one focus of the earth's orbit, and we are only 147.2 million km (91.4 million miles) away from the sun in late December and early January, while the earth-sun distance on July 1 is about 152.0 million km (94.4 million miles).

Solar energy approaches the earth as electromagnetic radiation at wavelengths between 0.25 and 5.0 μm. The intensity of the incoming solar irradiance on a surface normal to the sun's rays beyond the earth's atmosphere, at the average earth-sun distance, is designated as the solar constant, I_{SC}. Although the value of I_{SC} has not yet been precisely determined by verified measurements made in outer space, the most widely used value is 429.2 Btu/sq ft/hr and the current ASHRAE values are based on this estimate. More recent measurements made at extremely high altitudes indicate that I_{SC} is probably closer to 433.6 Btu/sq ft/hr. The unit of radiation that is widely used by meteorologists is the langley (Ly), equivalent to 1 kcal/sq cm. To convert from langleys/day to Btu/sq ft/day, multiply Ly/day by 3.67. To convert from W/sq m to Btu/sq ft/hr, multiply the electrical unit by 0.3172.

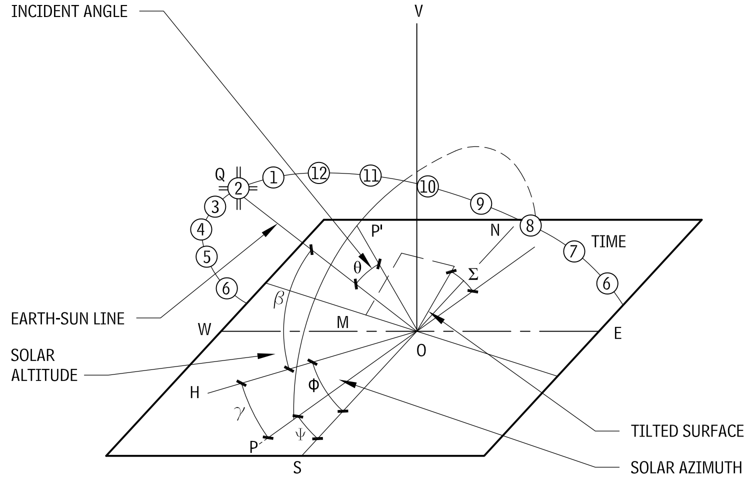
MINNEAPOLIS, MN
NEW YORK AREA
PHOENIX, AZ
MIAMI, FL
1.27



ANNUAL MOTION OF THE EARTH ABOUT THE SUN
1.29



SOLAR ANGLES WITH RESPECT TO A TILTED SURFACE
1.30



SOLAR ANGLES

At the earth's surface, the amount of solar radiation received and the resulting atmospheric temperature vary widely, primarily because of the daily rotation of the earth and the fact that the rotational axis is tilted at an angle of 23.45° with respect to the orbital plane. This tilt causes the changing seasons with their varying lengths of daylight and darkness. The angle between the earth-sun line and the orbital plane, called the solar declination, d, varies throughout the year, as shown in the following table for the 21st day of each month.

JAN	–19.9°	APR	+11.9°	JUL	+20.5°	OCT	–10.7°
FEB	–10.6°	MAY	+20.3°	AUG	+12.1°	NOV	–19.9°
MAR	0.0°	JUN	+23.5°	SEP	0.0°	DEC	–23.5°

Very minor changes in the declination occur from year to year, and when more precise values are needed, the almanac for the year in question should be consulted.

The earth's annual orbit about the sun is slightly elliptical, and so the earth-sun distance is slightly greater in summer than in winter. The time required for each annual orbit is actually 365.242 days rather than the 365 days shown by the calendar, and this is corrected by adding a 29th day to February for each year (except century years) that is evenly divisible by 4.

To an observer standing on a particular spot on the earth's surface, with a specified longitude, LON, and latitude, L, it is the sun that appears to move around the earth in a regular daily pattern. Actually, it is the earth's rotation that causes the sun's apparent motion. The position of the sun can be defined in terms of its altitude b above the horizon (angle HOQ) and its azimuth ϕ, measured as angle HOS in the horizontal plane.

At solar noon, the sun is, by definition, exactly on the meridian that contains the south-north line, and consequently the solar azimuth ϕ is 0.0°. The noon altitude β is:

$$\beta = 90° - L + \delta$$

Because the earth's daily rotation and its annual orbit around the sun are regular and predictable, the solar altitude and azimuth may be readily calculated for any desired time of day as soon as the latitude, longitude, and date (declination) are specified.

SHADOW CONSTRUCTION WITH TRUE SUN ANGLES

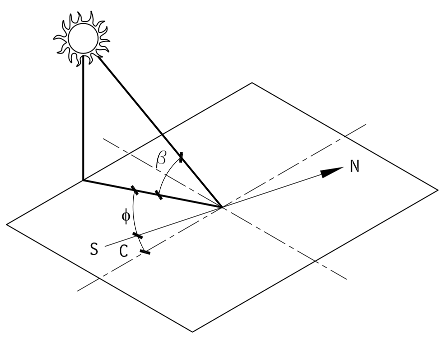
Required information: angle of orientation in relation to north-south axis (C), azimuth ϕ, and altitude angle β of the sun at the desired time (Figure 1.31).

Step 1. Lay out building axis, true south, and azimuth ϕ of the Sun Plan.

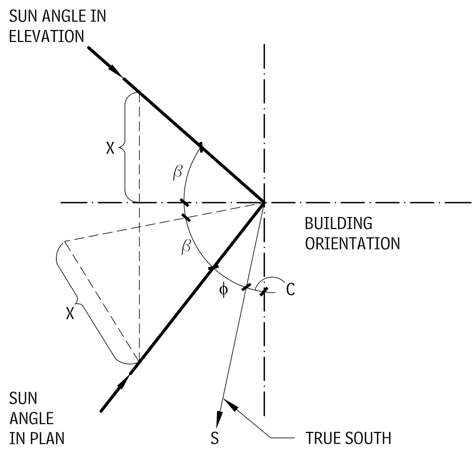
Step 2. Lay out altitude β upon azimuth ϕ. Construct any perpendicular to ϕ. From the intersection of this perpendicular and ϕ project a line perpendicular to the elevation plane (building orientation). Measure distance X along this line from the elevation plane. Connect the point at distance X from the elevation plane to the center to construct sun elevation β (Figure 1.32).

Step 3. Use Sun Plan ϕ + C and sun elevation β to construct shadows in plan and elevation in the conventional way (Figure 1.33).

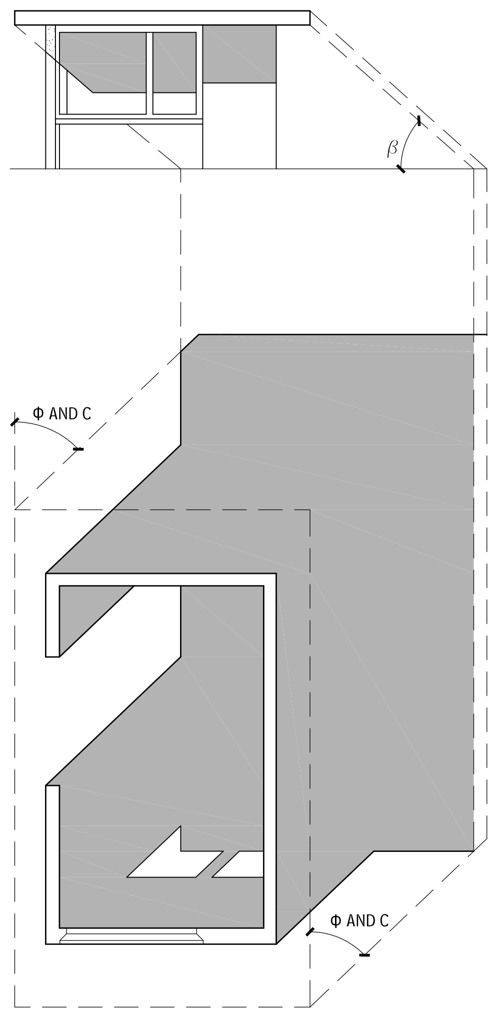
STEP 1
1.31



STEP 2
1.32



STEP 3
1.33



NOTE

1.29 The tilt of the earth's axis with respect to the ecliptic axis causes the changing seasons and the annual variations in number of hours of daylight and darkness.
1.30 Q designates the sun's position so OQ is the earth-sun line, while OP is the normal to the tilted surface and OP′ is perpendicular to the intersection OM, between the tilted surface and the horizontal plane.

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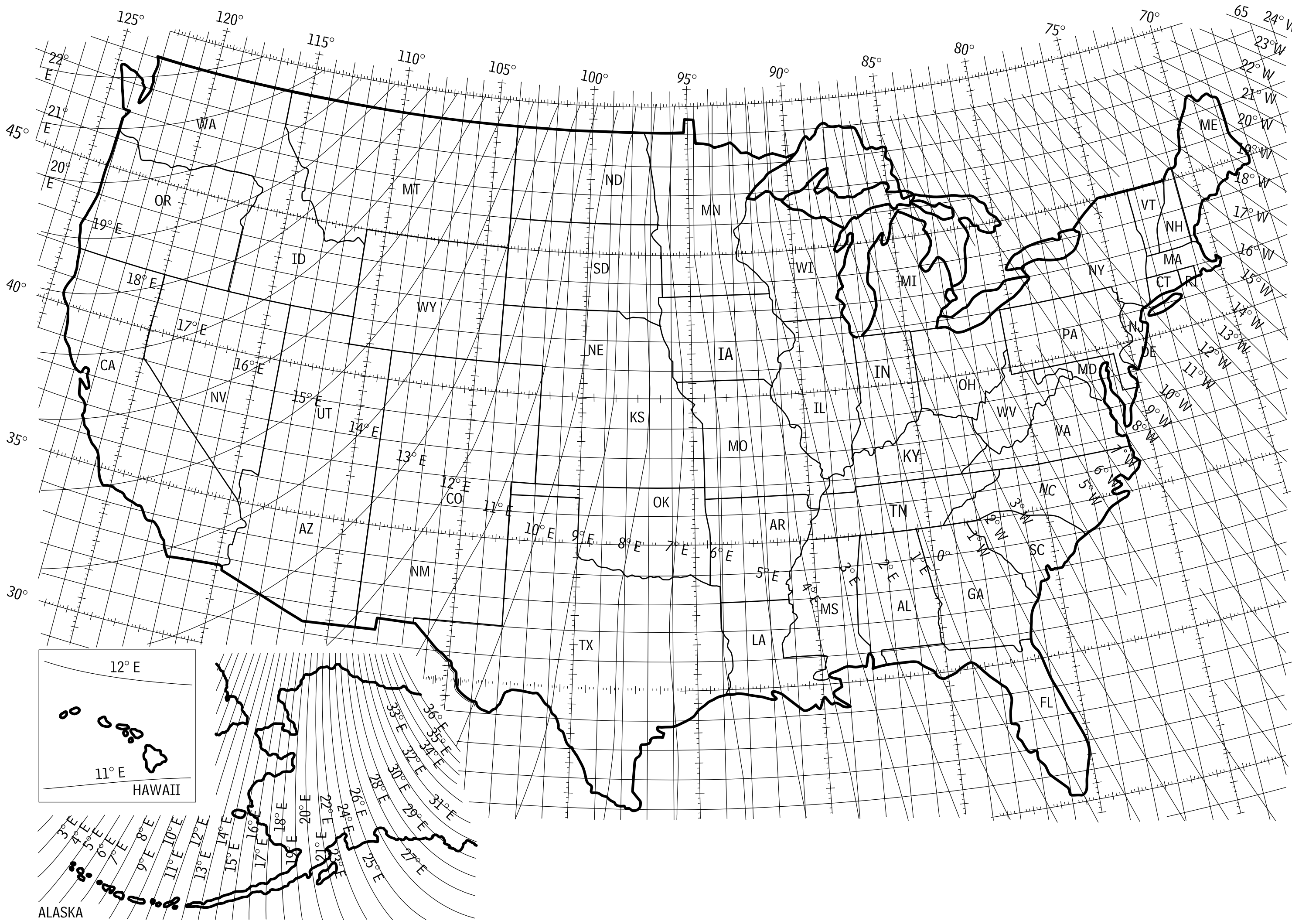
ORIENTATION AND TRUE NORTH

ISOGONIC CHART OF THE UNITED STATES (FROM DEPARTMENT OF THE INTERIOR GEODETIC SURVEY 1975)
1.34



COMPASS ORIENTATION

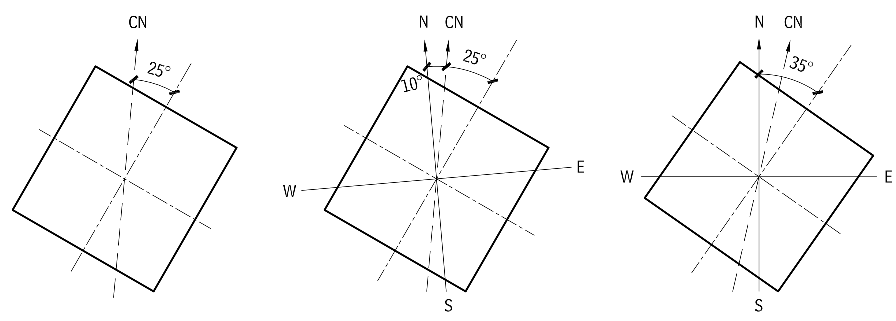
The map in Figure 1.34 is the isogonic chart of the United States. The wavy lines from top to bottom show the compass variations from the true north. At the lines marked E, the compass will point east of true north; at those marked W, the compass will point west of true north. According to the location, correction should be done from the compass north to find the true north.

For example, on a site in Wichita, Kansas, find the true north.

1. Find the compass orientation on the site.
2. Locate Wichita on the map. The nearest compass variation is the 10°E line.
3. Adjust the orientation correction to true north.

The graphical example in Figure 1.35 illustrates a building that lies 25° east with its axis from the compass orientation.

COMPASS ORIENTATION, VARIATION, AND CORRECTION
1.35



1. COMPASS ORIENTATION **2. COMPASS VARIATION** **3. ORIENTATION CORRECTION**

ORIENTATION PRINCIPLES

Orientation in architecture encompasses a large segment of different considerations. The expression "total orientation" refers to both the physiological and the psychological aspects of the problem.

On the physiological side, the factors that affect our senses and have to be taken into consideration are: the thermal impacts—the sun, wind, and temperature effects acting through our skin envelope; the visible impacts—the different illumination and brightness levels affecting our visual senses; and the sonic aspects—the noise impacts and noise levels of the surroundings influencing our hearing organs. In addition, our respiratory organs are affected by the smoke, smell, and dust of the environs.

On the psychological side, the view and the privacy are aspects in orientation that quite often override the physical considerations.

Above all, as a building is only a mosaic unit in the pattern of a town organization, the spatial effects, the social intimacy, and its relation to the urban representative directions—aesthetic, political, or social—all play a part in positioning a building.

THERMAL FORCES INFLUENCING ORIENTATION

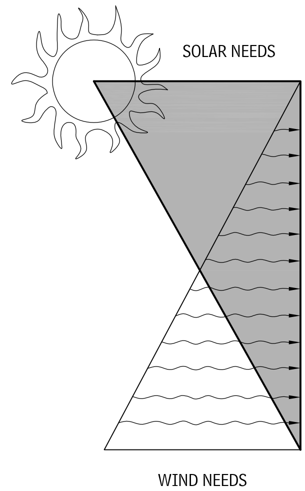
The climatic factors such as wind, solar radiation, and air temperature play the most eminent role in orientation. The position of a structure in northern latitudes, where the air temperature is generally cool, should be oriented to receive the maximum amount of sunshine without wind exposure. In southerly latitudes, however, the opposite will be desirable; the building should be turned on its axis to avoid the sun's unwanted radiation, and to face the cooling breeze instead. Figure 1.36 shows these regional requirements diagrammatically.

Adaptation for wind orientation is not of great importance in low buildings, where the use of windbreaks and the arrangement of openings in the high- and low-pressure areas can help to ameliorate the airflow situation. However, for high buildings, where the surrounding terrain has little effect on the upper stories, careful consideration has to be given to wind orientation.

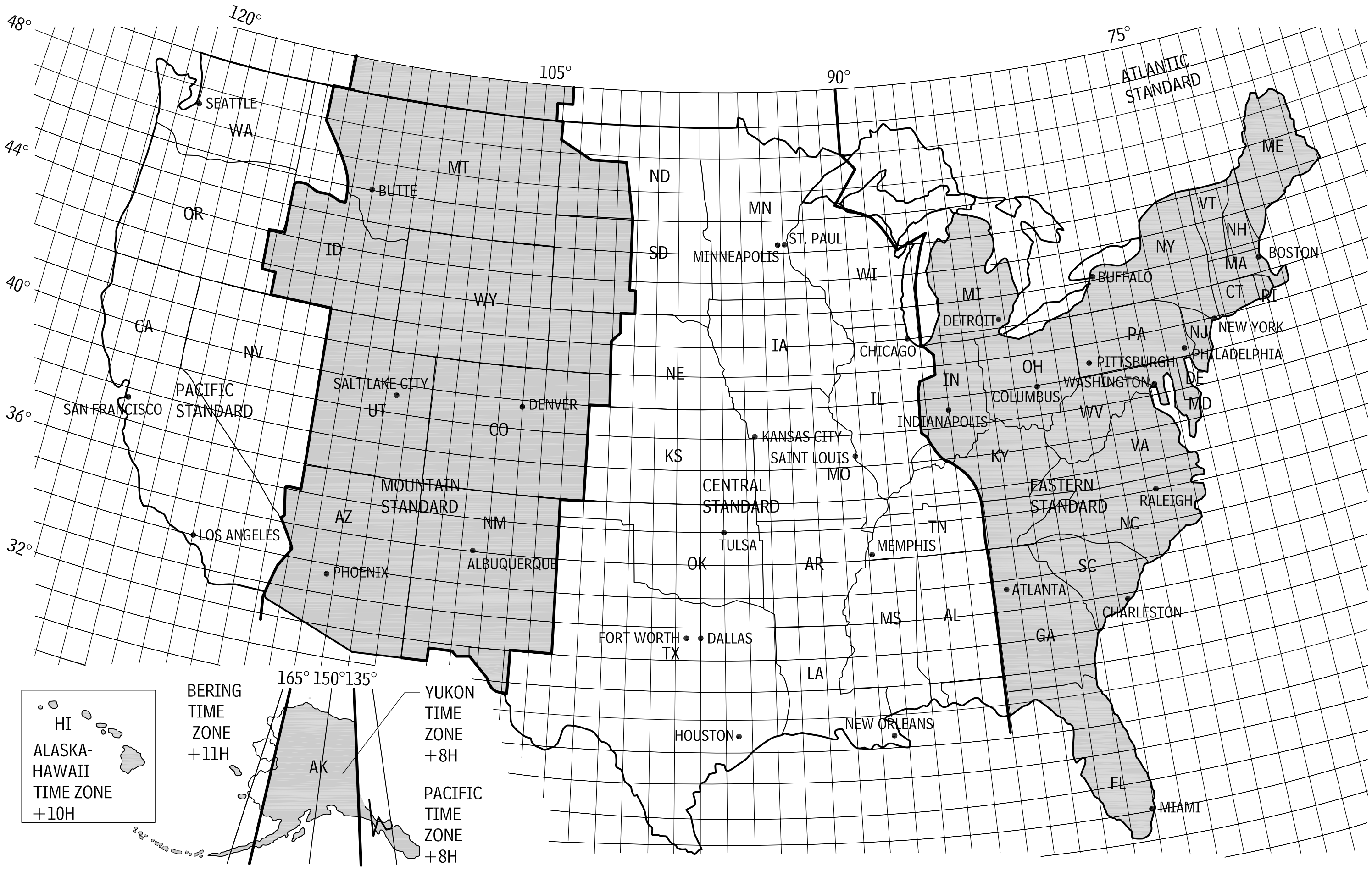
SOLAR TIME

Solar time generally differs from local standard or daylight saving time (DST), and the difference can be significant, particularly when DST is in effect.

THERMAL FORCES AND THEIR EFFECT ON REGIONAL REQUIREMENTS
1.36



STANDARD TIME ZONES OF THE UNITED STATES
1.37



NOTE

1.37 Greenwich Standard Time is 0 hr.

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Because the sun appears to move at the rate of 360°/24 hr, its apparent motion is 4 min/1° of longitude. The procedure for finding AST (apparent solar time), explained in detail in the references cited previously, is

$$AST = LST + ET + 4(LSM - LON)$$

where:

ET = equation of time (min)
LSM = local standard time meridian (degrees of arc)
LON = local longitude (degrees of arc)
4 = minutes of time required for 1.0° rotation of earth

The longitudes of the six standard time meridians that affect the United States are: Eastern ST, 75°; Central ST, 90°; Mountain ST, 105°; Pacific ST, 120°; Yukon ST, 135°; Alaska-Hawaii ST, 150°.

The equation of time is the measure, in minutes, of the extent by which solar time, as told by a sundial, runs faster or slower than civil or mean time, as determined by a clock running at a uniform rate. Table 1.38 gives values of the declination and the equation of time for the 21st day of each month of a typical year (other than a leap year). This date is chosen because of its significance on four particular days: (a) the winter solstice, December 21, which is the year's shortest day ($\delta = -23°27'$); (b) the vernal and autumnal equinoxes, March 21 and September 21, when the declination is zero and the day and night are equal in length; and (c) the summer solstice, June 21, which is the year's longest day ($\delta = +23°27'$).

EXAMPLES

Find AST at noon, local summer time, on July 21 for Washington, DC, longitude = 77°; and for Chicago, longitude = 87.6°.

SOLUTIONS

In summer, both Washington and Chicago use daylight saving time, and noon, local summer time, is actually 11:00 a.m., local standard time. For Washington, in the eastern time zone, the local standard time meridian is 75° east of Greenwich, and for July 21, the equation of time is –6.2 min. Thus noon, Washington summer time, is actually

$$11{:}00 - 6.2 \text{ min} + 4 \times (75 - 77) = 10{:}46 \text{ a.m.}$$

YEAR DATE, DECLINATION, AND EQUATION OF TIME FOR THE 21ST DAY OF EACH MONTH; WITH DATA[a] (A, B, C) USED TO CALCULATE DIRECT NORMAL RADIATION INTENSITY AT THE EARTH'S SURFACE
1.38

MONTH	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
Day of the year[b]	21	52	80	111	141	173	202	233	265	294	325	355
Declination (δ), degrees	–19.9	–10.6	0.0	+11.9	+20.3	+23.45	+20.5	+12.1	0.0	–10.7	–19.9	–23.45
Equation of time (min)	–11.2	–13.9	–7.5	+1.1	+3.3	–1.4	–6.2	–2.4	+7.5	+15.4	+13.8	+1.6
Solar noon	Late			Early			Late			Early		
A: Btu hr/sq ft	390	385	376	360	350	345	344	351	365	378	387	391
B: 1/m	0.142	0.144	0.156	0.180	0.196	0.205	0.207	0.201	0.177	0.160	0.149	0.142
C: dimensionless	0.058	0.060	0.071	0.097	0.121	0.134	0.136	0.122	0.092	0.073	0.063	0.057

For Chicago, in the central time zone, the local standard time meridian is 90°. Chicago lies 2.4° east of that line, and noon, Chicago summer time, is

$$11{:}00 - 6.2 \text{ min} + 4 \times 2.4 = 11{:}03 \text{ a.m.}$$

The hour angle, H, for these two examples would be

for Washington: $H = 0.25 \times (12{:}00 - 10{:}46) = 0.25 \times 74 = 18.8°$ east
for Chicago: $H = 0.25 \times (12{:}00 - 11{:}03) = 14.25°$ east

SOLAR PATH AND SOLAR ANGLE

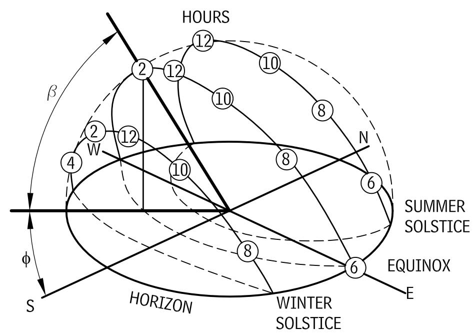
SOLAR ANGLES

The position of the sun in relation to specific geographic locations, seasons, and times of day can be determined by several methods. Model measurements, by means of solar machines or shade dials, have the advantage of direct visual observations. Tabulative and calculative methods have the advantage of exactness. However, graphic projection methods are usually preferred by architects, as they are easily understood and can be correlated to both radiant energy and shading calculations.

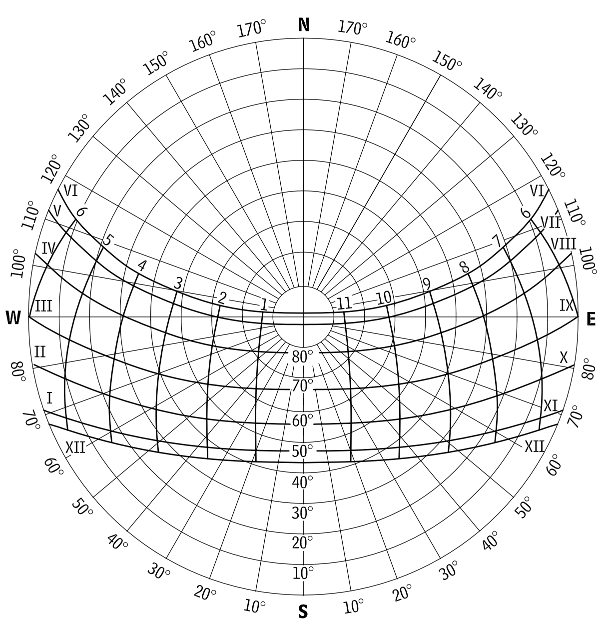
SOLAR PATH DIAGRAMS

A practical graphic projection is the solar path diagram method. Such diagrams depict the path of the sun within the sky vault as projected onto a horizontal place. The horizon is represented as a circle with the observation point in the center. The sun's position at any date and hour can be determined from the diagram in terms of its altitude and azimuth. (See Figure 1.39.) The graphs are constructed in equidistant projection. The altitude angles are represented at 10° intervals by equally spaced concentric circles; they range from 0° at the outer circle (horizon) to 90° at the center point. These intervals are graduated along the south meridian to 180° at the north meridian. These intervals are graduated along the periphery. The solar bearing will be to the east during morning hours, and to the west during afternoon hours.

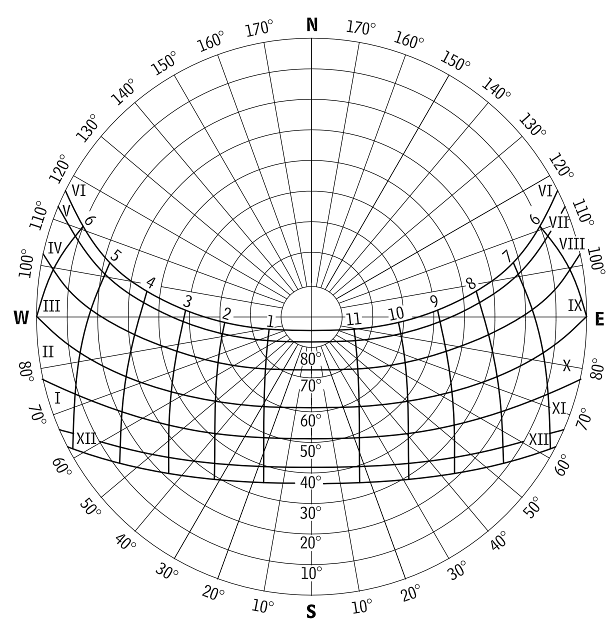
SOLAR ANGLE DIAGRAM
1.39



24° N LATITUDE
1.40



28° N LATITUDE
1.41



NOTES

1.38 a. A is the apparent solar irradiation at air mass zero for each month; B is the atmospheric extinction coefficient; C is the ratio of the diffuse radiation on a horizontal surface to the direct normal irradiation.
b. Declinations are for the year 1964.

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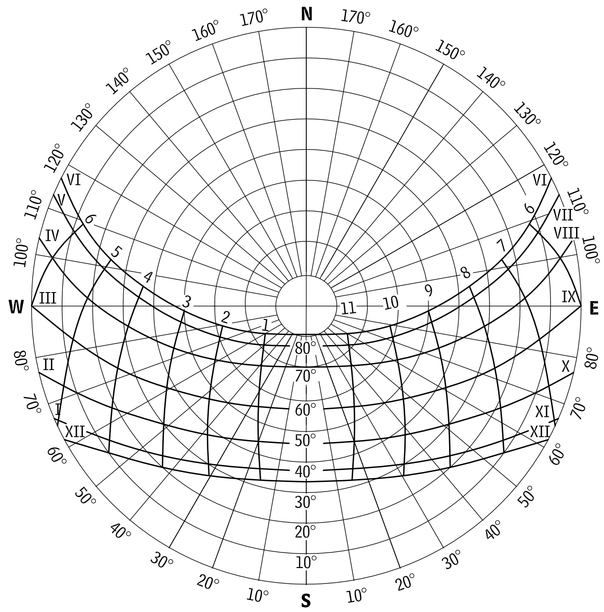
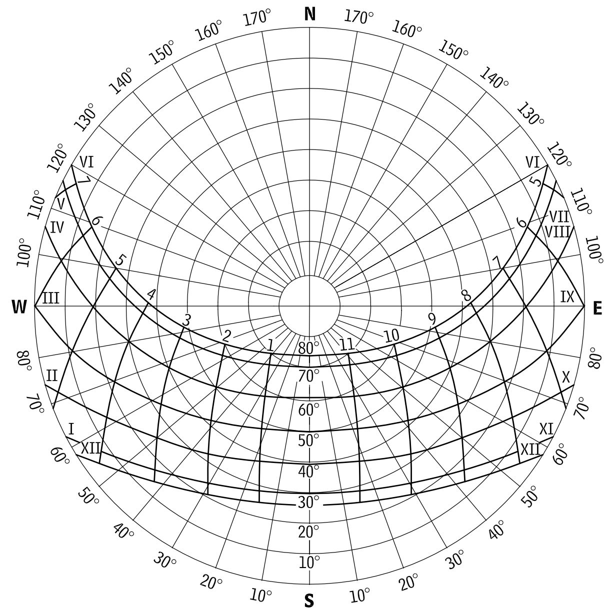
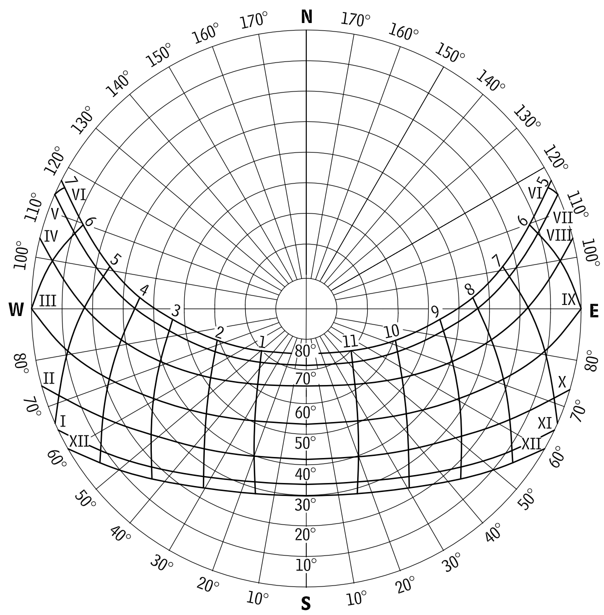
32° N LATITUDE
1.42



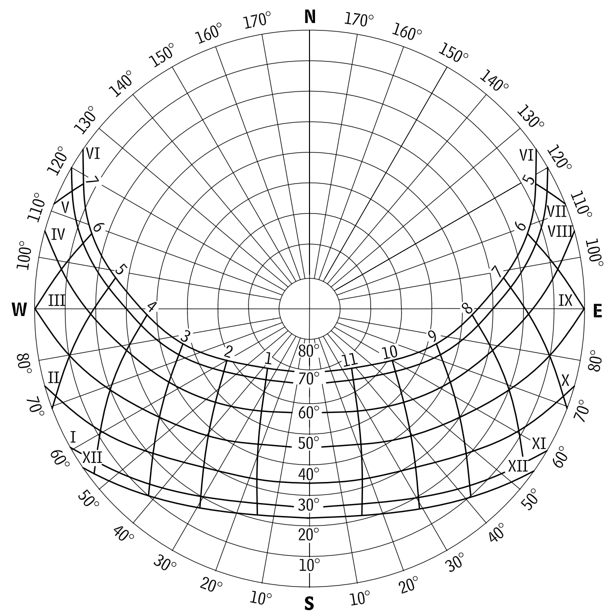
40° N LATITUDE
1.44



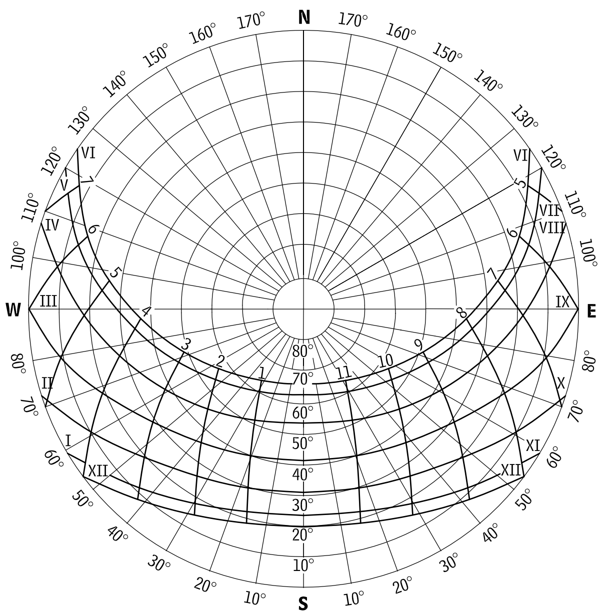
36° N LATITUDE
1.43



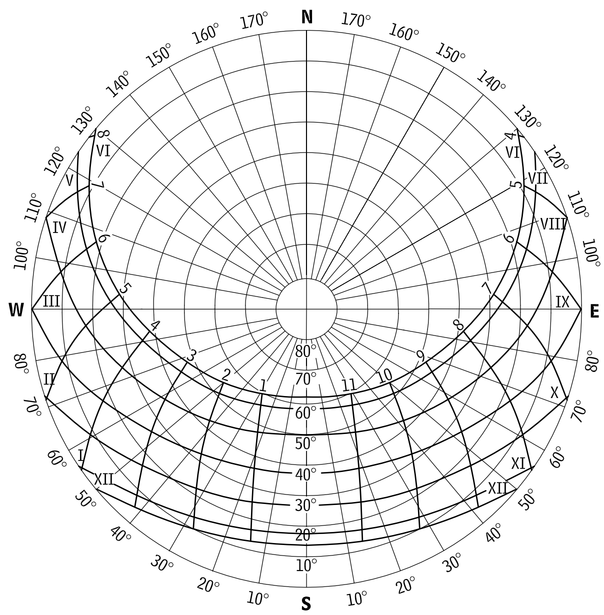
44° N LATITUDE
1.45



48° N LATITUDE
1.46



52° N LATITUDE
1.47



The earth's axis is inclined 23°27′ to its orbit around the sun and rotates 15° hourly. Thus, from all points on earth, the sun appears to move across the sky vault on various parallel circular paths with maximum declinations of ± 23°27′. The declination of the sun's path changes in a cycle between the extremes of the summer solstice and winter solstice. Thus the sun follows the same path on two corresponding dates each year. Due to irregularities between the calendar year and the astronomical data, here a unified calibration is adapted. The differences, as they do not exceed 41′, are negligible for architectural purposes.

The elliptical curves in the diagrams represent the horizontal projections of the sun's path. They are given on the 21st day of each month. Roman numerals designate the months. A cross grid of curves graduate the hours indicated in arabic numerals. Eight solar path diagrams are shown at 4 degree intervals from 24° N to 53° N latitude.

EXAMPLE

Find the sun's position on Columbus, Ohio, on February 21, 2 p.m.:

1. Locate Columbus on the map. The latitude is 40° N.
2. In the 40° sun path diagram, select the February path (marked with II), and locate the 2-hr line. Where the two lines cross is the position of the sun.
3. Read the altitude on the concentric circles (32°) and the azimuth along the outer circle (35°30′ W).

SOLAR POSITION AND HEAT GAIN

CALCULATION OF SOLAR POSITION

The solar position to any location and time can be accurately calculated by relating the spherical triangle formed by the observer's celestial meridian, the meridian of the sun, and the great circle passing through the zenith and the sun. The following formulas can be used to find the solar altitude and azimuth angles:

$$\sin \beta = \cos L \cos \delta \cos H + \sin L \sin \delta$$

$$\cos \phi = (\sin \beta \sin L - \sin \delta)/(\cos \beta \cos L)$$

where:

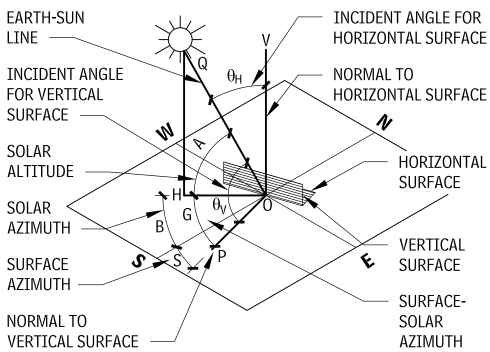
β = solar altitude above the horizon
L = latitude of the location; conventionally negative for southern hemisphere latitudes
δ = declination of the sun at the desired date, which is the angle between the earth-sun line and the equatorial plane (north declinations are conventionally positive; south declinations negative)
H = hour angle of the sun = 0.25 × (number of minutes from local solar noon); H is zero at solar noon and changes 15° per hour
ϕ = solar azimuth, which is the angular distance measured from the south between the south-north line and the projection of the earth-sun line in the horizontal plane

DECLINATION OF THE SUN
1.48

DATE	DECLINATION	CORRESP. DATE	DECLINATION	UNIFIED CALIBR.
June 21	+23°27′			+23°27′
May 21	+20°09′	July 21	+20°31′	+20°20′
Apr. 21	+11°48′	Aug. 21	+12°12′	+12°00′
Mar. 21	+0°10′	Sep. 21	+0°47′	+0°28′
Feb. 21	–10°37′	Oct. 21	–10°38′	–10°38′
Jan. 21	–19°57′	Nov. 21	–19°53′	–19°55′
Dec. 21	–23°27′			–23°27′

SOLAR-SURFACE ANGLES

SOLAR-SURFACE ANGLES
1.49



The direction of the earth-sun line OQ is defined by the solar altitude A (angle HOQ) and the solar azimuth B (angle HOS). These can be calculated when the location (latitude), date (declination), and time of day (hour angle) are known. The surface azimuth S is the angle SOP between the south-north line SON and the normal to the surface OP. The surface-solar azimuth G is the angle HOP.

The angle of incidence θ depends on the orientation and tilt of the irradiated surface. For a horizontal surface, θ_H is the angle QOV between the earth-sun line OQ and the vertical line OV. For the vertical surface shown as facing SSE, the angle of incidence θ_V is the angle QOP between the earth-sun line OQ and the normal to the surface, OP. For surfaces such as solar collectors, which are generally tilted at some angle T upward from the horizontal, the incident angle θt may be found from the equation:

$$\cos \theta t = \cos A \cos S \sin T + \sin A \cos T$$

CALCULATION OF SOLAR IRRADIATION

It is necessary to know the amount of solar energy falling on exposed surfaces in order to evaluate the importance of solar shading. Because shading devices primarily protect surfaces from direct solar irradiation, only these energy calculations are described here.

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The magnitude of direct solar irradiation is, first of all, a function of the sun's altitude and the apparent solar constant and atmospheric extinction coefficient. The latter two parameters take into account the annual variation of the earth-sun distance and the atmospheric water vapor content. The intensity of direct solar irradiation under clear atmospheric conditions at normal incidence can be calculated by:

$$I_{DN} = A \exp(-B/\sin \beta)$$

where:

I_{DN} = direct normal solar intensity at the earth's surface on clear days
exp = base of natural logarithm
A = apparent solar constant or apparent normal incidence intensity at air mass zero
B = atmospheric extinction coefficient

Table 1.50 indicates direct normal solar irradiation on clear days as a function of solar altitude on the solstices and the equinoxes.

I_{DN} AS A FUNCTION OF SOLAR ALTITUDE (BTU/SQ FT/HR) 1.50

β	JUNE 21	MAR. 21/SEPT. 21	DEC. 21
5	33	55	77
10	106	142	173
15	156	195	226
20	189	228	258
25	212	250	279
30	229	266	294
40	251	286	314
50	264	298	325
60	272	306	332
70	277	310	336
80	280	313	339
90	281	314	339

SOLAR IRRADIATION

The direct irradiation received by any given surface is also a function of the angle of incidence of the solar beam relative to that surface. The angle of incidence is the angle between the direct solar rays and a line normal to the irradiated surface.

For horizontal surfaces, the cosine of the angle of incidence is equal to the sine of the solar altitude. The direct irradiation on horizontal surfaces is thus calculated by:

$$I_{DH} = I_{DN} \times \sin \beta$$

For vertical surfaces, the incident angle depends on the solar altitude and the surface-solar azimuth. The surface-solar azimuth (δ) is the angular distance between the solar azimuth and the azimuth of the surface. The surface azimuth is the angle between south and the normal to the surface, measured counterclockwise from south. The direct irradiation on vertical surfaces can thus be calculated by:

$$I_{DV} = I_{DN} \times \cos \beta \cos \gamma$$

In Tables 1.51–1.56, calculated values of solar position in degrees, and direct irradiation in Btu/sq ft/hr are given for horizontal surfaces and various vertical orientations. The tables indicate values for 26° N to 46° N latitude at 4° intervals on the solstices and the equinoxes.

26° N LATITUDE INCIDENT DIRECT SOLAR RADIATION 1.51

JUNE 21										
				BTU/SQ FT/HR						
A.M.		ALT	AZM	S	SE	E	NE	N	SW	HOR
6	6	10.05	111.30		42	98	96	38		19
7	5	22.82	105.97		91	180	164	52		79
8	4	35.93	101.15		110	193	164	38		143
9	3	49.24	96.45		107	171	134	19		199
10	2	62.69	91.17		87	126	91	3		243
11	1	76.15	82.61	9	53	66	41			271
12		87.45	0.00	13	9				9	281
	P.M.	β	ϕ	S	SW	W	NW	N	SE	HOR
MAR./SEPT. 21										
				BTU/SQ FT/HR						
A.M.		ALT	AZM	S	SE	E	NE	N	SW	HOR
6	6	0.00	90.00							
7	5	13.45	83.30	21	138	175	109			42
8	4	26.71	75.80	56	196	222	117			115
9	3	39.46	66.33	88	205	202	80			181
10	2	51.11	52.79	114	186	150	25			233
11	1	60.25	31.43	130	148	79			36	266
12		64.00	0.00	135	95				95	277
	P.M.	β	ϕ	S	SW	W	NW	N	SE	HOR
DEC. 21										
				BTU/SQ FT/HR						
A.M.		ALT	AZM	S	SE	E	NE	N	SW	HOR
6	6									
7	5	2.23	62.48	5	10	9	3			
8	4	13.76	54.88	120	206	171	36			51
9	3	24.12	45.30	177	252	179	1			113
10	2	32.66	33.01	212	248	138			53	162
11	1	38.46	17.65	232	216	74			112	194
12		40.55	0.00	239	169				169	204
	P.M.	β	ϕ	S	SW	W	NW	N	SE	HOR

30° N LATITUDE INCIDENT DIRECT SOLAR RADIATION 1.52

JUNE 21										
				BTU/SQ FT/HR						
A.M.		ALT	AZM	S	SE	E	NE	N	SW	HOR
6	6	11.48	110.59		50	113	110	42		25
7	5	23.87	104.30		97	184	163	47		84
8	4	36.60	98.26		117	194	157	28		146
9	3	49.53	91.79		117	171	125	5		200
10	2	62.50	83.46	14	99	126	79			243
11	1	76.11	67.48	27	66	66	27			270
12		83.45	0.00	32	23				23	279
	P.M.	β	ϕ	S	SW	W	NW	N	SE	HOR
MAR./SEPT. 21										
				BTU/SQ FT/HR						
A.M.		ALT	AZM	S	SE	E	NE	N	SW	HOR
6	6	0.00	90.00							
7	5	12.95	82.37	23	137	170	104			40
8	4	25.66	73.90	63	199	218	110			109
9	3	37.76	63.43	100	212	200	71			173
10	2	48.59	49.11	128	196	148	14			223
11	1	56.77	28.19	147	159	79			48	254
12		60.00	0.00	153	108				108	265
	P.M.	β	ϕ	S	SW	W	NW	N	SE	HOR
DEC. 21										
				BTU/SQ FT/HR						
A.M.		ALT	AZM	S	SE	E	NE	N	SW	HOR
6	6									
7	5	0.38	62.40							
8	4	11.44	54.15	110	185	152	30			38
9	3	21.27	44.12	177	246	171			4	96
10	2	29.28	31.73	217	248	134			59	143
11	1	34.64	16.77	240	221	72			119	173
12		36.55	0.00	247	175				175	183
	P.M.	β	ϕ	S	SW	W	NW	N	SE	HOR

34° N LATITUDE INCIDENT DIRECT SOLAR RADIATION
1.53

JUNE 21										
				BTU/SQ FT/HR						
A.M.		ALT	AZM	S	SE	E	NE	N	SW	HOR
6	6	12.86	109.78		57	126	121	45		
7	5	24.80	102.54		103	188	162	42		34
8	4	37.07	95.28		125	195	151	18		99
9	3	49.49	87.10	9	127	171	115			158
10	2	61.79	76.00	31	111	125	67			205
11	1	73.17	55.10	46	79	66	14			234
12		79.45	0.00	51	36				23	244
	P.M.	β	φ	S	SW	W	NW	N	SE	HOR
MAR./SEPT. 21										
				BTU/SQ FT/HR						
A.M.		ALT	AZM	S	SE	E	NE	N	SW	HOR
6	6	0.00	90.00							
7	5	12.39	81.48	25	134	165	99			37
8	4	24.49	72.11	69	201	215	103			103
9	3	35.89	60.79	110	217	197	61			163
10	2	45.89	45.92	142	204	147	3			211
11	1	53.21	25.60	163	170	78			60	241
12		56.00	0.00	169	120				120	251
	P.M.	β	φ	S	SW	W	NW	N	SE	HOR
DEC. 21										
				BTU/SQ FT/HR						
A.M.		ALT	AZM	S	SE	E	NE	N	SW	HOR
6	6									
7	5									
8	4	9.08	53.57	93	155	126	23			25
9	3	18.38	43.12	173	236	162			8	79
10	2	25.86	30.65	219	246	130			63	123
11	1	30.81	16.05	245	223	70			123	152
12		32.55	0.00	253	179				179	162
	P.M.	β	φ	S	SW	W	NW	N	SE	HOR

38° N LATITUDE INCIDENT DIRECT SOLAR RADIATION
1.54

JUNE 21										
				BTU/SQ FT/HR						
A.M.		ALT	AZM	S	SE	E	NE	N	SW	HOR
6	6	14.18	108.87		64	137	130	47		37
7	5	25.60	100.70		109	190	160	36		93
8	4	37.33	92.25		133	195	144	8		149
9	3	49.13	82.47	23	137	171	105			199
10	2	60.58	69.06	48	122	125	55			238
11	1	70.61	45.67	64	92	66	1			262
12		75.45	0.00	70	50				50	270
	P.M.	β	φ	S	SW	W	NW	N	SE	HOR
MAR./SEPT. 21										
				BTU/SQ FT/HR						
A.M.		ALT	AZM	S	SE	E	NE	N	SW	HOR
6	6	0.00	90.00							
7	5	11.77	80.63	26	130	158	93			33
8	4	23.20	70.43	75	202	210	96			96
9	3	33.86	58.38	120	222	194	53			153
10	2	43.03	43.16	155	212	145			7	198
11	1	49.57	23.52	177	180	77			71	227
12		52.00	0.00	185	131				131	236
	P.M.	β	φ	S	SW	W	NW	N	SE	HOR
DEC. 21										
				BTU/SQ FT/HR						
A.M.		ALT	AZM	S	SE	E	NE	N	SW	HOR
6	6									
7	5									
8	4	6.69	53.12	69	114	92	16			13
9	3	15.44	42.30	164	221	149			10	61
10	2	22.40	29.74	216	240	124			66	103
11	1	26.96	15.45	246	222	68			126	130
12		28.55	0.00	255	180				180	139
	P.M.	β	φ	S	SW	W	NW	N	SE	HOR

42° N LATITUDE INCIDENT DIRECT SOLAR RADIATION
1.55

JUNE 21										
				BTU/SQ FT/HR						
A.M.		ALT	AZM	S	SE	E	NE	N	SW	HOR
6	6	15.44	107.87		70	147	137	47		43
7	5	26.28	98.78		115	192	157	30		96
8	4	37.38	89.19	3	140	196	136			150
9	3	48.45	77.96	36	146	170	95			196
10	2	58.95	62.79	64	133	125	43			233
11	1	67.64	38.62	82	105	66			12	256
12		71.45	0.00	88	63				63	263
	P.M.	β	φ	S	SW	W	NW	N	SE	HOR
MAR./SEPT. 21										
				BTU/SQ FT/HR						
A.M.		ALT	AZM	S	SE	E	NE	N	SW	HOR
6	6	0.00	90.00							
7	5	11.09	80.63	27	126	151	87			30
8	4	21.81	79.84	79	201	205	89			88
9	3	31.70	56.21	128	225	191	45			142
10	2	40.06	40.79	166	218	143			16	184
11	1	45.88	21.82	190	188	76			81	211
12		48.00	0.00	198	140				140	220
	P.M.	β	φ	S	SW	W	NW	N	SE	HOR
DEC. 21										
				BTU/SQ FT/HR						
A.M.		ALT	AZM	S	SE	E	NE	N	SW	HOR
6	6									
7	5									
8	4	4.28	52.82	35	58	46	8			4
9	3	12.46	41.63	148	197	131			12	44
10	2	18.91	29.00	209	229	116			66	82
11	1	23.09	14.96	242	217	65			125	107
12		24.55	0.00	253	179				179	115
	P.M.	β	φ	S	SW	W	NW	N	SE	HOR

46° N LATITUDE INCIDENT DIRECT SOLAR RADIATION
1.56

JUNE 21										
				BTU/SQ FT/HR						
A.M.		ALT	AZM	S	SE	E	NE	N	SW	HOR
6	6	16.63	106.77		76	155	142	47		48
7	5	26.82	96.80		121	194	154	23		99
8	4	37.22	86.15	13	147	195	129			149
9	3	47.47	73.66	50	155	169	85			192
10	2	56.95	57.25	80	144	124	31			226
11	1	64.40	33.33	99	116	65			24	248
12		67.45	0.00	106	75				75	255
	P.M.	β	φ	S	SW	W	NW	N	SE	HOR
MAR./SEPT. 21										
				BTU/SQ FT/HR						
A.M.		ALT	AZM	S	SE	E	NE	N	SW	HOR
6	6	0.00	90.00							
7	5	10.36	79.09	27	120	142	81			26
8	4	20.32	67.45	83	199	199	82			80
9	3	29.42	54.27	134	227	187	37			130
10	2	36.98	38.75	175	223	140			24	169
11	1	42.14	20.43	201	195	75			89	194
12		44.00	0.00	210	148				148	203
	P.M.	β	φ	S	SW	W	NW	N	SE	HOR
DEC. 21										
				BTU/SQ FT/HR						
A.M.		ALT	AZM	S	SE	E	NE	N	SW	HOR
6	6									
7	5									
8	4	1.86	52.65	3	5	4	1			
9	3	9.46	41.12	122	162	107			12	27
10	2	15.41	28.41	194	212	105			63	61
11	1	19.23	14.56	232	207	60			122	84
12		20.55	0.00	244	173				173	92
	P.M.	β	φ	S	SW	W	NW	N	SE	HOR

Contributor:
Gary L. Powell, Ph.D., Salt River Project, Phoenix, Arizona.

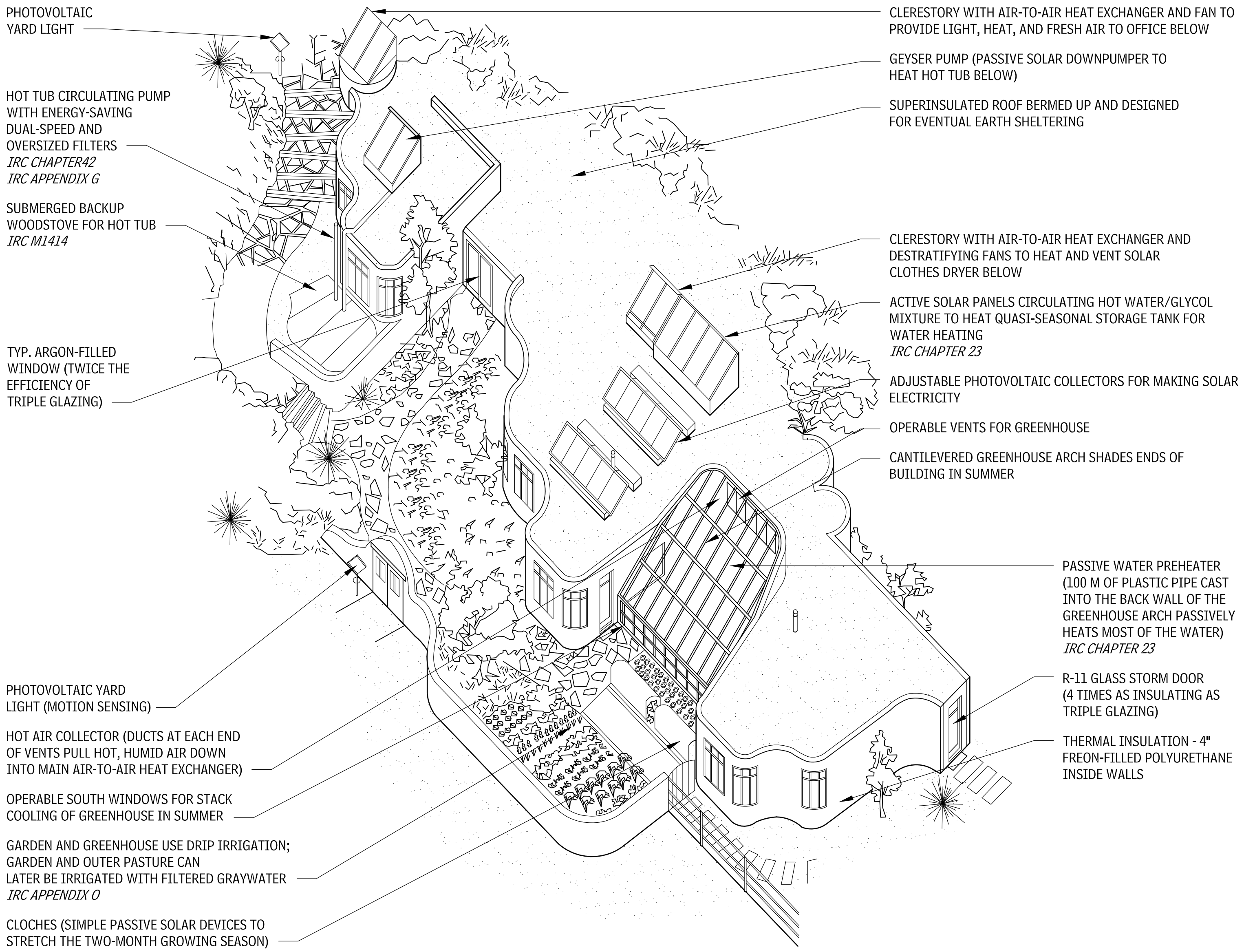
RESOURCE CONSERVATION

RESOURCE CONSERVATION METHODS AND SYSTEMS

Choosing building materials containing recycled materials is but one step in the process of environmentally conscious design. Sensitive environmental design takes the holistic view, regarding every aspect of how a building works in its context. Consideration must be given to how a building performs and relates to its surroundings throughout its life, before (design and specification), during (construction), and after (lifetime maintenance and energy costs) it is built. The following guidelines can be used for designing with resource conservation goals:

- Design with nature's patterns in mind, so the building works with them and the resources of its site rather than overpowering and controlling them. The following methods will help you achieve this goal:
  - *Building and site planning.* To achieve the goal of overall environmental design, it is critical to orient the building to the landscape at the site. Working with site features will allow you to take advantage of natural systems, such as ventilation by means of windows and chimneys or full-spectrum light sources.
  - *Earth-sheltered design.* Solar heat and light can be used to reduce the nonrenewable energy requirements of a building. The temperature-moderating feature of the earth is an aspect of the surrounding environment often ignored. Through earth berms, earth-covered roofs, and underground design, a building can make use of the consistent 55° F± of the earth below the local frost line or at least the inherent R-value of earth material. A well-designed earth-sheltered structure also reduces the need for exterior maintenance of building materials.
- Preserving existing site features may benefit the local habitat and make the building harmonize with the site.
  - *Tree, plant, and soil preservation.* Establish environmental priorities for the building site. Inventory natural features such as viable trees and shrubs and wetland areas. Trees provide an enormous environmental benefit to the health of buildings (shading, etc.), sites (soil enrichment from leaves, etc.), and birds and other wildlife. Locate buildings, driveways, and land to be disturbed during construction far enough from existing trees to avoid root compaction. A good rule of thumb is to stay out of the drip line of a tree during construction. Have a landscape architect, arborist, forester, or environmental consultant assist in the survey.
  - *Construction and demolition site waste recycling or reuse.* The construction of a single-family home in the United States generates 2.5 tons of waste. Since landfill overcrowding has

ENERGY-SAVING SYSTEMS (THE ROCKY MOUNTAIN INSTITUTE, SNOWMASS, COLORADO)
1.57



caused dumping fees to increase significantly, it is becoming economically feasible to recycle construction and demolition wastes. Identify materials that could be used more efficiently, salvaged, reused on site, or recycled. Common materials that generally can be recycled from construction sites are (with percentages based on total site waste volume): wood (27%), cardboard/paper (18%), gypsum board (15%), insulation (9%), roofing (8%), metals (7%), concrete/asphalt rubble (6%), landscaping debris (5%), and miscellaneous (5%). These are national averages, and each site will be different. Identify positions for recycling bins on site so materials can be separated as they are recovered. Prevent storm sewer and groundwater pollution and reduce soil erosion with sensitive design and site construction methods.

- Energy-efficient design should reduce or eliminate nonrenewable fossil fuel consumption for heating, cooling, and lighting. Although it is good to create a building with resource conservative materials, it is critical to ensure that once the building is built it either continues to conserve energy resources or uses renewable energy resources throughout its life. Consider using durable, low-maintenance materials. Where practical, design full-cycle systems, such as solar water heating, that will capture renewable energy on site. The following equipment can help achieve this goal:
  - *Heat recovery ventilators.* This system extracts the heat from the air as it is exhausted and transfers it to incoming air (or the reverse in the summer). This system allows a tight, energy-efficient building to be ventilated but still retain the heat energy used to maintain the indoor environment. Depending on the climate, this system can be up to 80% efficient in recovering energy and is recommended for either very cold or very hot, humid climates. Consult with a mechanical engineer or equipment manufacturer.
  - *Ground source heat pump.* Like earth-sheltered building design, this system takes advantage of the stability of underground temperatures. Long lengths of copper tubing are buried either horizontally or vertically in the earth and circulated with a heat-exchanging medium.

PRIORITIES FOR SUSTAINABLE BUILDINGS

It is rarely possible to do everything we would like to reduce the environmental impact of building projects. It takes time to research alternative design and construction systems, new materials may lack proven track records, costs may be excessive, or clients may not be interested. Therefore, it makes sense to determine which efforts will do the most good.

Material selection is one of the most visible green building strategies and often the easiest to point to, but it is not usually the most important. Outlined in this topic are other factors to consider and a list of priorities in green design.

A BASIS FOR ESTABLISHING PRIORITIES

To make objective decisions about which investments of time and money will contribute the most toward reducing environmental impact, consider several related factors:

The most significant environmental risks of the project. These may be global in nature or more specific to the region or site. Prioritizing them is difficult as they often are unrelated so cannot be compared directly.

How buildings contribute to these risks and how significantly the measures we adopt can help the situation.

The specific opportunities presented by each individual project. For some projects, an architect can dramatically affect building performance in one area with little investment, while addressing other environmental impacts may prove very expensive and only minimally effective.

The available resources and agenda of the client. Often measures can be taken at no additional cost—some may even save money—to reduce environmental impacts. Other measures might increase the first cost of a building but save money over time.

All these measures are important and should be implemented whenever feasible within the constraints of a particular project.

SAVE ENERGY

Design and build energy-efficient buildings. Ongoing energy use is the single greatest source of environmental impact from a building; thus, buildings designed for low energy use can have a significant effect on the environment. An integrated design approach takes advantage of energy savings that result from interaction between separate building elements (e.g., windows, lighting, and mechanical systems).

Sample strategies include:

- In buildings with skin-dominated energy loads, incorporate high levels of insulation and high-performance windows to make buildings as airtight as possible.
- Minimize cooling loads through careful building design, glazing selection, lighting design, and landscaping.
- Meet energy demand with renewable energy resources.
- Install energy-efficient appliances, lighting, and mechanical equipment.

RECYCLE BUILDINGS

Reuse existing buildings and infrastructure instead of developing open space. Existing buildings often contain a wealth of material and cultural resources and contribute to a sense of place. As well, the workmanship and quality of materials that went into them is almost impossible to replicate today.

Sample strategies include:

- Maximize energy efficiency when restoring or renovating buildings.
- Handle any hazardous materials appropriately (lead paint, asbestos, etc.).

CREATE COMMUNITY

Design communities to reduce dependence on the automobile and foster a sense of community. Address transportation as part of the effort to reduce environmental impacts. Even the most energy-efficient, state-of-the-art passive solar house will carry a big environmental burden if its occupants have to get in a car to commute 20 miles to work.

Sample strategies include:

- Design communities that provide access to public transit, pedestrian corridors, and bicycle paths.
- Work to change zoning to permit mixed-use development so homeowners can walk to the store or to work.
- Plan home offices in houses to permit telecommuting.
- Site buildings to enhance the public space around them and maximize pedestrian access.

REDUCE MATERIAL USE

Optimize design to make use of smaller spaces, and utilize materials efficiently. Smaller is better, relative to the environment. For all materials, using less is almost always preferable, provided the durability or structural integrity of a building is not compromised. Reducing the surface area of a building reduces energy consumption. Reducing waste both helps the environment and reduces cost.

Sample strategies include:

- Reduce the building footprint and use space more efficiently.
- Simplify building geometry to save energy and materials.
- Design building dimensions to optimize material use and reduce waste.

PROTECT AND ENHANCE THE SITE

Preserve or restore local ecosystems and biodiversity. In fragile ecosystems or ecologically significant environments, such as old-growth forests or remnant stands of native prairie, this might be the highest priority.

Sample strategies include:

- Protect wetlands and other ecologically important areas on a parcel of land to be developed.
- On land that has been ecologically damaged, work to reintroduce native species.
- Protect trees and topsoil during construction.
- Avoid pesticide use. Provide construction detailing that minimizes the need for pesticide treatments.
- With on-site wastewater systems, provide responsible treatment to minimize groundwater pollution.

SELECT LOW-IMPACT MATERIALS

Specify low environmental impact, resource-efficient materials. Most environmental impacts associated with building materials occur before installation. Raw materials have been extracted from the ground or harvested from forests, pollutants have been emitted during manufacture, and energy has been invested during production.

Sample strategies include:

- Avoid materials that generate a lot of pollution (volatile organic chemicals [VOCs], hydrochlorofluorocarbons [HCFCs], etc.) during manufacture or use.
- Specify materials with low embodied energy (energy used in resource extraction, manufacturing, and shipping).
- Specify materials salvaged from other uses.
- Avoid materials that unduly deplete limited natural resources.
- Avoid materials made from toxic or hazardous constituents (benzene, arsenic, etc.).

MAXIMIZE LONGEVITY

Design for durability and adaptability. The longer a building lasts, the longer the period you will have over which to amortize the building's environmental impacts. Designing and building a structure that will last a long time necessitates consideration of how the building can be modified to satisfy changing needs.

Sample strategies include:

- Specify durable materials. This is usually even more important than selecting materials with low embodied energy.
- Assemble the materials to prevent premature decay.
- Design for easy maintenance and replacement of less durable components.
- Design for adaptability, especially in commercial buildings.
- Allocate an appropriate percentage of building funds for ongoing maintenance and improvement.

SAVE WATER

Design buildings and landscapes that use water efficiently. This is largely a regional issue. In some parts of the country, reducing water use is much higher on the priority list.

Sample strategies include:

- Install water-efficient plumbing fixtures and appliances.
- Collect and use rainwater.
- Provide low water use landscaping (xeriscaping).
- Separate and use graywater for landscape irrigation where codes permit.
- Provide for groundwater recharge through effective storm water infiltration designs.

Contributors:
Richard J. Vitullo, AIA, Oak Leaf Studio, Crownsville, Maryland.
AIA Environmental Resource Guide.

MAKE THE BUILDING HEALTHY

Provide a safe, comfortable indoor environment. Although some people separate the indoor and outdoor environments, the two are integrally related, and the health of its occupants should be ensured in any "sustainable" building.

Sample strategies include:

- Design air distribution systems for easy cleaning and maintenance.
- Avoid mechanical equipment that could introduce combustion gases into the building.
- Avoid materials with high rates of VOC off-gassing such as standard particleboard, some carpets and adhesives, and certain paints.
- Control moisture to minimize mold and mildew.
- Provide for continuous ventilation in all occupied buildings. In cold climates, heat recovery ventilation will reduce the energy penalty of ventilation.
- Give occupants some control of their environment with features like operable windows, task lighting, and temperature controls.

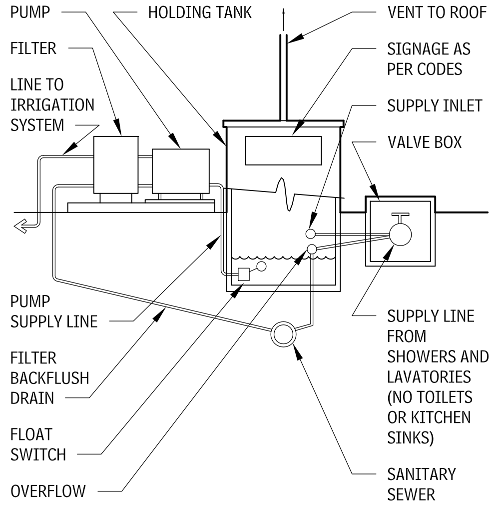
MINIMIZE CONSTRUCTION AND DEMOLITION WASTE

Return, reuse, and recycle job site waste. For more and more materials, sorting and recycling job site waste pays off economically. It also can generate a good public image.

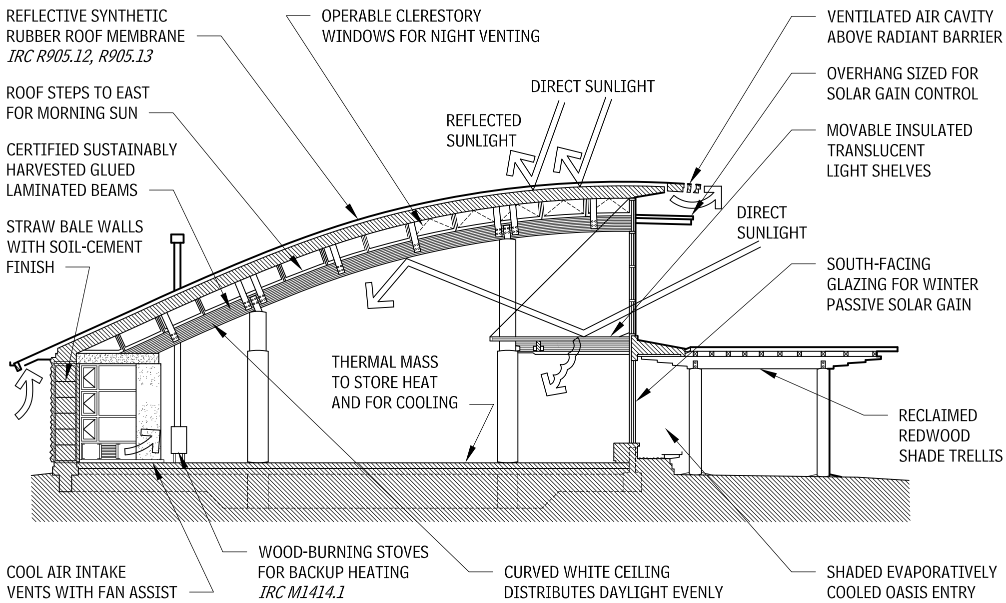
Sample strategies include:

- Sort construction and demolition waste for recycling.
- Donate reusable materials to nonprofit or community groups that can use them to build or improve housing stock.

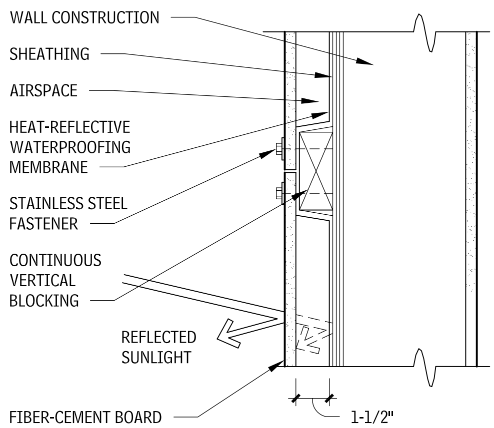
GRAYWATER SYSTEM
1.61



SUSTAINABLE BUILDING EXAMPLE—REAL GOODS SOLAR LIVING CENTER
1.58

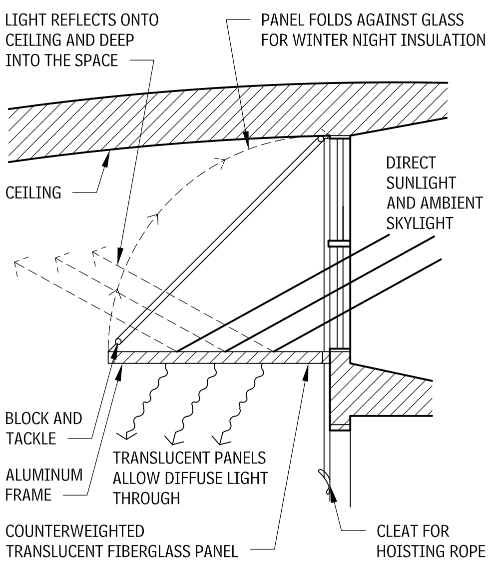


VENTILATED WALL CAVITY
1.62

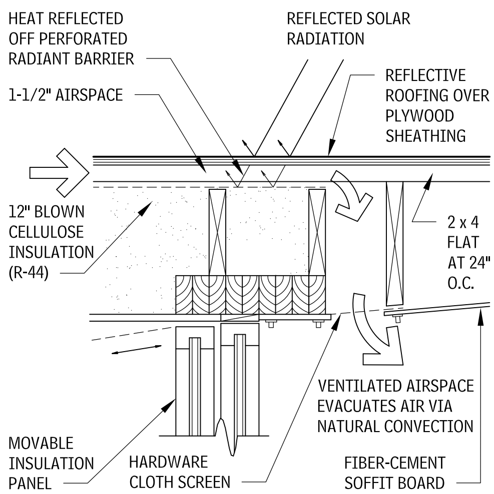


PLAN DETAIL

LIGHT SHELF
1.59



VENTILATED AIR CAVITY DETAIL AT ROOF
1.60



NOTES

1.59 Aluminum frame light shelves with insulated translucent fiberglass panels fold against the windows to increase insulation values and reflect light deep into the space.
1.60 A ventilated air cavity located over a perforated radiant barrier will carry heat from reflected radiation out of the building before it can migrate down through the insulation.
1.61 Graywater systems can be used to "recycle" lavatory and shower water for subsurface plant irrigation.
1.62 Ventilated wall cavities effectively reduce unwanted heat buildup in extreme cooling climates. An inner membrane reflects solar gain from low afternoon sun and waterproofing.

Contributors:
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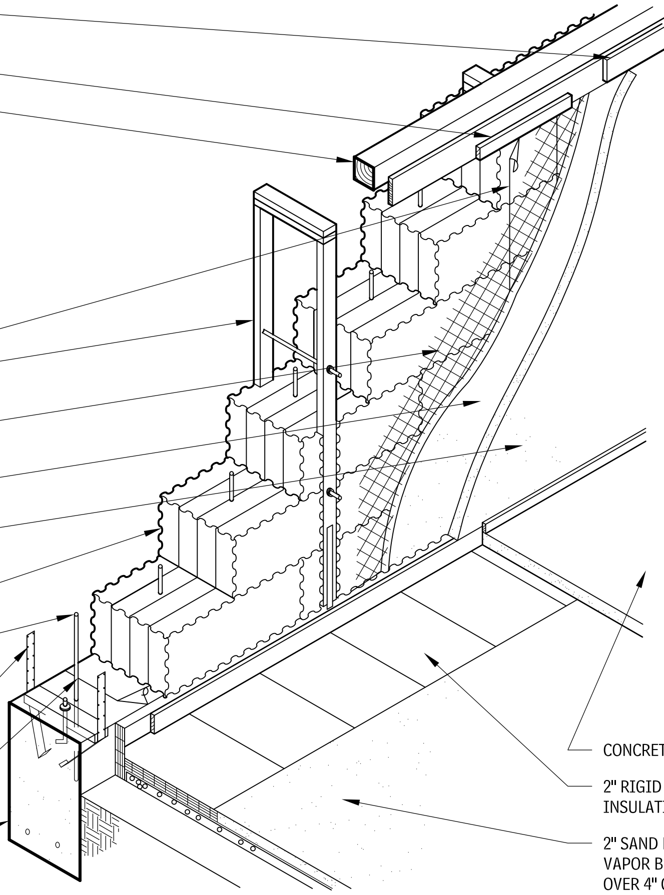
Environmental Building News, Brattleboro, Vermont.
Real Goods Solar Living Center, Hopland, California.

STRAW BALE CONSTRUCTION SYSTEM
1.63



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DAYLIGHTING

GENERAL GUIDELINES

Ample daylight is available throughout most of North America for lighting interior spaces during a large portion of the working day. Daylight is often used for ambient lighting but may be used for critical visual tasks as well, in each case supplemented with electric light as needed. Daylight is thought by most to be psychologically desirable, and there is growing evidence that it is biologically beneficial and can contribute to enhanced task performance. The variability of the intensity and color of daylight over time stimulates the visual senses, and the view and visual connection with the outdoors that accompanies many daylighting designs is almost universally desired. Proper use of daylight can help reduce unnecessary energy use for electric lighting and cooling, if the electric lighting system is controlled with on-off switching or dimming.

DESIGN STRATEGIES

Daylight has always been an important element of architectural design, and in the era before cheap electric light, it was often a major determinant of a building's form. In buildings today, daylighting strategies are used in a variety of contexts, both as a strategy to define the quality of experience in an architectural space as well as in a more utilitarian role to reduce unneeded use of electric lighting.

Daylighting usually supplements or complements an electric lighting design, so it is essential that the two be fully integrated. For a given building program and climate, it may be feasible and desirable to create spaces in which the primary light source is daylight. In others, electric lighting will be the primary source, supplemented by daylight. The decision to make daylight the primary source will directly influence other design decisions, such as the size of the floor plan, the arrangement of spaces within the floor plan, and the overall massing and configuration of the building. Designs intended to maximize daylight use will either provide perimeter access to each space or utilize low-rise designs that allow skylights to provide daylight. Atriums and light courts can provide some useful daylight in low-rise buildings of two to five stories. The best strategy for daylighting in high-rise buildings is to ensure that no spaces on the floor plan are more than 30 ft from a daylighting source.

DESIGN PROCESS

To be successful, daylighting requires the integration of all major building systems. Daylighting issues should be well defined in the programmatic or schematic phases of design and monitored through construction to occupancy. Early planning is essential, since it may be difficult and costly to add features later in design development. Many architects and lighting designers are skilled in resolving daylighting design issues and trade-offs. However, in designs that push the state of the art, present unusual conditions, or have quantitative performance expectations that must be met, it may be appropriate to use a daylighting consultant with expertise in many of the computer-based tools now available.

Although critical design decisions related to plan and section will be determined early, many seemingly small decisions are made in the final stages of design and bid preparation that can influence the success of a daylighted space. These include issues such as interior finishes, furniture specifications, and installation details for controls. After construction is complete, most daylighting systems involving controls and operable systems should be calibrated and commissioned. The final step in the process is to ensure that facility managers and occupants understand the operation of the complete system.

SOURCE

The origin of all daylight is the sun, but the light may reach a work space via a number of paths. Direct sunlight is intense and varies substantially as the sun's position changes throughout the day (up to 10,000 footcandles [fc]). Daylight from a clear sky can be 10 to 25% of the intensity of direct sunlight (1,000–2,500 fc). Daylight under partly cloudy conditions can be highly variable; daylight

NOTES

1.63 a. The two basic methods of straw bale construction are load bearing (the bales carry the weight of the roof) and non–load bearing (typically a post-and-beam system). The illustration shows one of many accepted techniques.
b. Straw bale construction lends itself to a variety of styles and finishes. The raw material is the waste of another industry: cultivation of grain for food. Straw bale construction is a long-lasting, durable building method. Homesteaders in the Great Plains started building with bales in the late 19th century, and many of these structures still stand today.
c. When laid flat and stacked like bricks in a "running bond" pattern, plastered or stuccoed straw bale walls are ±24 in. thick. They have an insulating value of as much as R-57, three times the value of typical insulated wood walls. These thick walls present opportunities for niches, deep window sills and seating areas, and "truth windows."

Contributor:
Arkin Tilt Architects, Albany, California.

under full overcast conditions can be 5 to 10% of sun conditions (500–1,000 fc). Data on daylight availability for various cities and building orientations can be found in several references. Daylight availability at locations in the United States is influenced by latitude and weather patterns. Traditionally overcast climates such as Seattle may have sunshine only 40% of the year while regions like Palm Springs, California, have sunny conditions for 90% of the year.

Exterior conditions (ground, trees, water, adjacent buildings) can all influence interior daylight levels. In some cases, the architect can control these conditions to enhance daylight levels. Nearby trees will filter daylight, and adjacent buildings may obstruct the view of the sky and block direct sun. In built-up urban environments, windows on lower floors of buildings adjacent to multistory buildings will receive little useful daylight. The south facade of a light colored building that is struck by direct sunlight can become a very bright light source for the north-facing windows of an adjacent building.

Orientation has a major impact on available daylight and influences the degree of difficulty in controlling sunlight on a facade. North orientations in most North American locations receive direct sunlight only in the early morning or late evening in summer. South facades have the longest exposure to direct sun. Given the high altitude angle of the sun in summer, sun control on the south facade is readily addressed with properly sized overhangs. In winter, low-altitude sun must be controlled by shades, blinds, or other means. Low-altitude direct sun on east and west orientations causes glare and cooling problems and is the most difficult to control. Exterior vertical fins or interior vertical blinds provide control but allow some view.

Not only does the intensity of daylight and sunlight vary, but also the color or appearance varies as well. The characteristic yellow-white of direct sunlight becomes redder as the sun moves lower in the sky and travels through more air mass. The north sky on a clear day can be deep blue, a result of scattering processes in the atmosphere. Cloudy and hazy skies typically have a uniform white appearance. Daylight is a full-spectrum source that, notwithstanding its variability, will faithfully render the color of most materials, something that not all electric lamps can do. The sun and sky are powerful sources of ultraviolet (UV) light that can damage pigments in paintings and furnishings. Design in light-sensitive applications such as museums must pay particular attention not only to the UV characteristics of daylight but also to the visible light portions, which are responsible for some fading. Certain glazing options will reduce these negative effects of light to acceptable levels.

ENVELOPE AND ROOM DESIGN

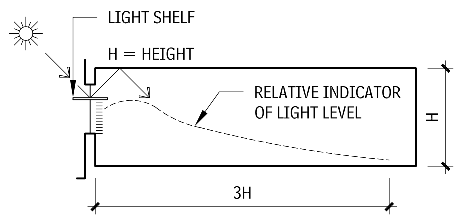
Building envelope and room design details can be thought of as the light fixture that controls the distribution of daylight in a space. Envelope decisions include the size, shape, and location of the fenestration and the type of glazing and shading system. Room geometry, size, and surface properties also influence achievable daylight levels.

There are practical limits to room size beyond which conventional window systems are ineffective. The depth limitation of a daylighted zone with windows becomes a fundamental constraint and design determinant. For designs that use diffuse daylight from the sky, clouds, or surrounding environment, it is difficult to provide adequate daylight when the depth of the space is more than 1.5 or 2 times the height of the head of the window. (Designs that redirect daylight and sunlight to the ceiling using light shelves or light-redirecting glazings might be able to extend this to 3 times the ceiling height.)

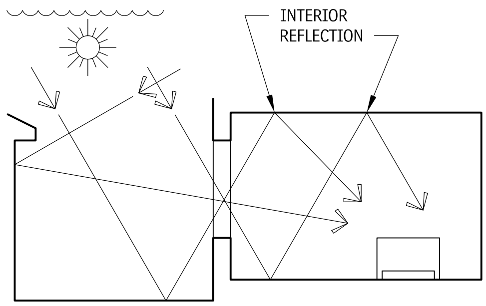
A window of a given size will provide the most daylight deep in a space when it is located as high as possible on the wall. Light-colored walls and ceilings maximize the daylight levels in the rear of a space. Deeper spaces need larger windows to provide more light, but larger windows have other drawbacks. The uniformity ratio between the daylight level in the front and back of a room becomes larger as the room becomes deeper and should not exceed a ratio of 10:1. A splayed window reveal will reduce glare and ease the transition from bright exterior to darker interior. Sloped ceiling surfaces may improve daylight utilization, but their biggest benefit is typically the greater ceiling height at the perimeter. Interior walls and partitions will reduce daylight levels. Use of light colors or glazed interior partition walls will help mitigate this undesired impact.

Distribution of daylight in a space can be greatly improved if it is introduced from multiple apertures—for example, windows on two sides of a space, or windows and clerestories, or windows and skylights. In low-rise buildings, diffusing skylights are an effective way to daylight a space. The skylights are diffusing and their spacing is optimized based on ceiling height. More elaborate toplighting systems can utilize a variety of roof monitors or clerestories.

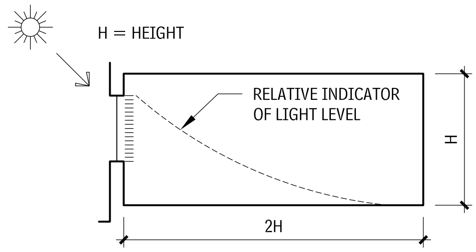
REDIRECTED DAYLIGHT PENETRATION INTO A SPACE
1.64



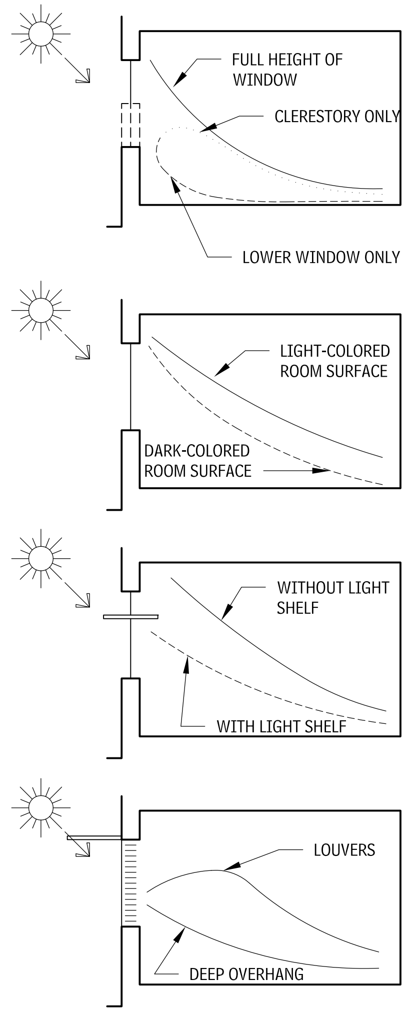
LIGHT PATHS TO A WORK SPACE
1.65



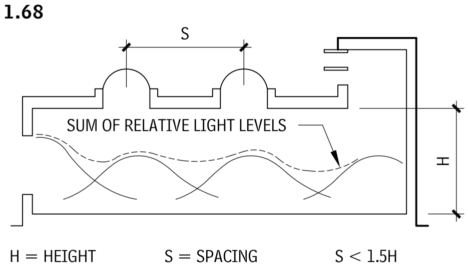
DIFFUSE DAYLIGHT PENETRATION INTO A SPACE
1.66



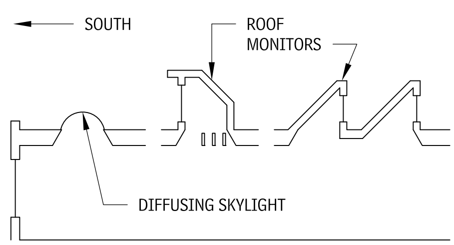
RELATIVE INDICATOR OF LIGHT LEVELS WITH VARIOUS DESIGNS
1.67



LIGHT LEVELS WITH SKYLIGHTS
1.68



TOPLIGHTING SYSTEM TYPES
1.69



GLAZING AND SHADING DESIGN

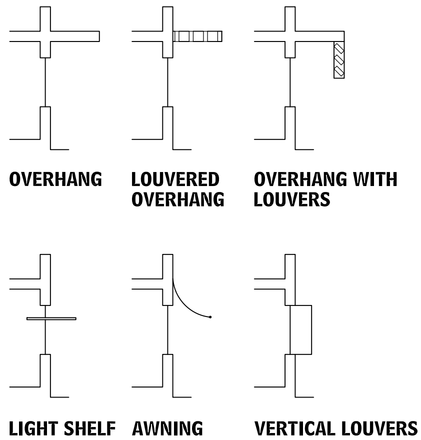
Selection of a glazing system can have a tremendous impact on the performance of a daylighting system. The glazing controls the amount of light admitted, its intensity, and its directionality as it enters a space. The challenge is to admit adequate light to achieve illumination objectives without creating glare or causing overheating or large cooling loads. Numerous glazing systems are available to control solar gain and the transmittance, distribution, and color of light. Conventional clear and tinted glazings are still offered, but low-E coated glass or plastic and spectrally selective low-E glazings are becoming more popular. These glazings reduce winter heat loss and reduce cooling load in summer with little additional loss of daylight. They are excellent for admitting daylight, but glare control must be provided with shading systems. In an insulating glass unit, both low-E and tinted glazings can be used to optimize performance. Highly reflective glass with very low transmittance has a role in highly glazed facades with limited sun control options, but occupants complain about poor views through these glazings on overcast days or at night. Glazings with a frit layer provide some sun and glare control.

Some new options available to designers promise greater optical control capability. Prismatic glazings can redirect light, and between-glass elements can provide varying degrees of light control and solar control.

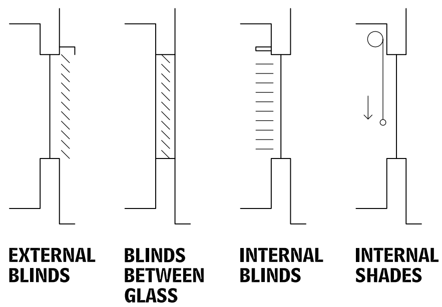
Adequate control of sun and glare is often difficult to provide with glazing selection alone. Architectural shading solutions are typically part of the exterior facade. Other shading devices can be positioned outside the glazing, between glazings, or at the interior surface. Shading systems can be static or operable, controlled either by occupants or with motorized, automated controls. Shading systems that are intended to block sunlight alone can be dark, but light-colored systems should be used if the intent is to provide diffuse daylight. Overhangs, fins, shade screens, venetian blinds, vertical blinds, miniature louvers, and roller shades are commonly used systems. Operable systems are often preferred because they can take advantage of the variability of sunlight and daylight. In open-plan offices, it may be desirable to use motorized, automated shading controls; in single-person offices, it is likely that the occupant will use the shading controls as needed.

New types of light-redirecting systems, such as prismatic glazings, provide shading at a task location by redirecting the sunlight to the ceiling. Light shelves can also provide shading as well as some control of daylight levels and light distribution. Simple, flat light shelves with white, diffuse surfaces will provide some shading near the window and brighten the ceiling near the window but will not redirect light deep into a room. The size, shape, location, and surface properties of light shelves will have a significant influence on their ability to redistribute light in a space.

WINDOW SHADING DEVICES
1.70



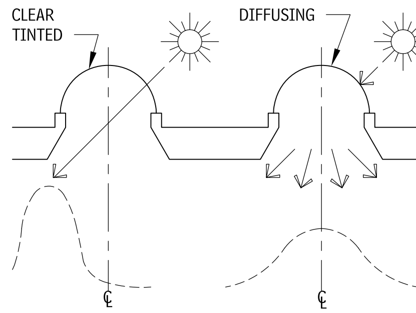
SHADING DEVICES NEAR GLAZING SURFACE
1.71



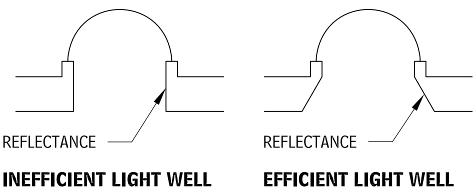
SKYLIGHTS AND SLOPED GLAZING

Light distribution from skylights is intrinsically more uniform than that from windows. Skylight solutions range from simple vacuum-formed plastic domes to sophisticated, multilayer glazing products. Skylights in work areas with office tasks should provide diffuse light so that its distribution is relatively uniform. Nondiffusing glazings will result in visual hot spots and glare. Light diffusion can be achieved by using diffusing plastic bubble skylights, high-transmission glazing with a diffusion screen below, some of the fritted glasses or laminates with diffusing layers, or exterior shading systems. Light wells provide a transition from the roof plane to the lower ceiling plane or the space below. The geometry and surface properties of the wells determine the total light loss. Light wells can reduce the amount of light entering a space from as little as 10% to as much as 85%. Splayed wells with high reflectance finishes are the best performers. Adequate daylight in most climates is provided with skylight areas of about 4 to 8% with relatively high transmittance glazing. Larger areas with proportionally lower transmittance will work as well. A completely glazed roof or sloped glazing may be used but the transmittance of the glazing should be about 5%. The importance of controlling heat gain depends in part on the occupancy of the space and the climate. In most skylight and sloped glazing designs, safety codes require laminated glass or alternative safety solutions; consult code authorities or manufacturers.

DAYLIGHT DISTRIBUTION WITH SKYLIGHT TYPES
1.72



LIGHT WELL DESIGN
1.73



SEISMIC DESIGN

GENERAL GUIDELINES

According to the theory of plate tectonics, the earth's crust is divided into constantly moving plates. Earthquakes occur when, as a result of slowly accumulating pressure, the ground slips abruptly along a geological fault plane on or near a plate boundary. The resulting waves of vibration within the earth create ground motions at the surface, which, in turn, induce movement within buildings. The frequency, magnitude, and duration of the ground motion, physical characteristics of the building, and geology of a site determine how these forces affect a building.

DESIGN JUDGMENT

In an earthquake, buildings designed to the minimum levels required by model codes often sustain damage. Early discussions with an owner should explore the need to limit property loss in an earthquake and the desirability of attempting to ensure continued building operation immediately afterward. To achieve these results, it may be necessary to make design decisions more carefully tuned to the seismic conditions of a site than code requires.

SEISMIC CODES

The seismic provisions of the 2009 IRC apply to one- and two-family dwellings constructed in Design Categories D_0, D_1, and D_2. Other dwellings that are required to comply with the IRC that are constructed in Design Category C locations must comply with the seismic requirements of the code.

Refer to IRC Figure R301.2(2) for a map of the Seismic Design Categories. Seismic codes are constantly evolving, and architects should always consult the relevant code before beginning a project.

SEISMIC DESIGN CATEGORY DETERMINATION
1.74

CALCULATED S_{DS}	SEISMIC DESIGN CATEGORY
$S_{DS} \leq 0.17g$	A
$0.17g \leq S_{DS} \leq 0.33g$	B
$0.33g \leq S_{DS} \leq 0.50g$	C
$0.50g \leq S_{DS} \leq 0.67g$	D_0
$0.67g \leq S_{DS} \leq 0.83g$	D_1
$0.83g \leq S_{DS} \leq 1.17g$	D_2
$1.17g \leq S_{DS}$	E

Contributor:
Stephen Selkowitz, Lawrence Berkeley National Laboratory, Berkeley, California.

Another primary resource should be the National Earthquake Hazards Reduction Program (NEHRP), which seeks to mitigate earthquake losses in the United States. The NEHRP is the federal government's coordinated approach to addressing earthquake risks. NEHRP is managed as a collaborative effort among FEMA, the National Institute of Standards and Technology, the National Science Foundation, and the U.S. Geological Survey. NEHRP produces FEMA 232—Homebuilders' Guide to Earthquake Resistant Design and Construction.

TERMS

The seismic community has an extensive set of terms with which to describe common conditions in the field. Following is a short list of some of these terms and their definitions:

Base shear (static analysis). Calculated total shear force acting at the base of a structure, used in codes as a static representation of lateral earthquake forces; also referred to as "equivalent lateral force."

Design earthquake. Earthquake ground motion for which a building is designed.

Drift. Lateral deflection of a building or structure. Story drift is the relative movement between adjacent floors.

Ductility. The ability of a structural frame to bend but not break. Its ductility is a major factor in establishing the ability of a building to withstand large earthquakes. Ductile materials (steel in particular) fail only after permanent deformation has taken place. Good ductility requires special detailing of the joints.

Dynamic analysis. A structural analysis based on the vibration motion of a building. Dynamic analysis is time consuming and normally reserved for complex projects.

Forces, in-plane. Forces exerted parallel to a wall or frame.

Forces, out-of-plane. Forces exerted perpendicular to a wall or frame.

Maximum considered earthquake. The greatest ground shaking expected to occur during an earthquake at a site. These values are somewhat higher than those of the design earthquake, particularly in areas where seismic events are very infrequent. The code maps are based on earthquakes of this magnitude.

Re-entrant corner. The inside building corner of an L-, H-, X-, or T-shaped plan.

SITE DESIGN FOR SEISMIC AREAS

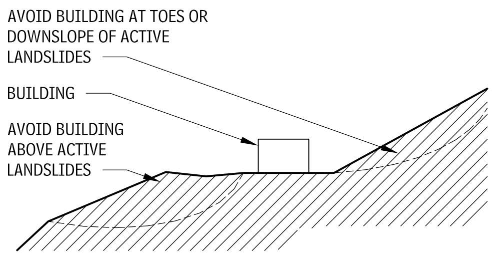
GENERAL GUIDELINES

Each building and site lies within a broader context of regional seismicity, localized geology, community vulnerability, and adjacent structures and land uses. Siting decisions, therefore, can have a significant impact on the overall seismic performance of a structure. This section focuses on the following criteria for siting a building:

- Avoid unstable sites.
- Avoid nonengineered fill.
- Avoid or design for sites that can subside or liquefy.
- Avoid building over surface faulting.
- Avoid adjacent hazardous buildings.
- Prevent battering from adjacent buildings.
- Create safe areas of refuge when redeveloping older buildings.

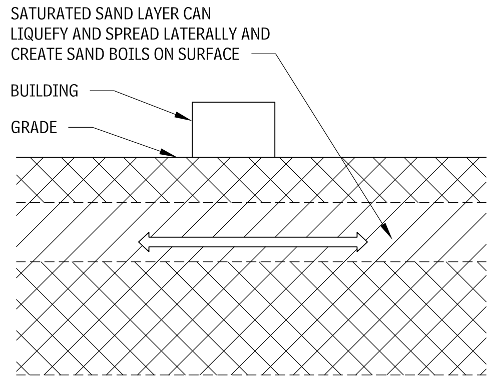
Decisions on appropriate land uses for a specific site, separation from active ground faulting, site stability, and separation from adjacent buildings are critical to performance. Although many of these factors have traditionally been considered city planning issues, the designer must also incorporate them into the architectural development of a seismically resistant building.

UNSTABLE SITES
1.77

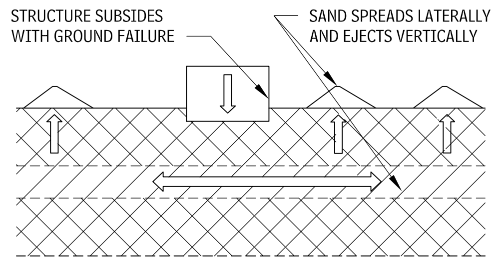


SITE SECTION

SUBSIDENCE OR LIQUEFACTION
1.79



SITE SECTION (BEFORE LIQUEFACTION)



SITE SECTION (AFTER EARTHQUAKE AND LIQUEFACTION)

DESIGN FOR RESISTING SEISMIC FORCES AND FOUNDATION ISSUES

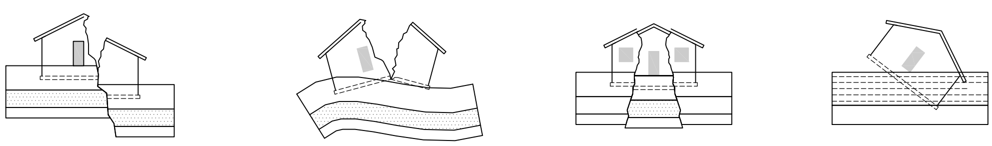
A design that resists seismic forces for a structure makes use of the lateral systems' ductility. Such ductile lateral systems are designed to deflect more under seismic loading than what would be expected from something such as wind loading. This allows for the use of smaller effective seismic design forces and more reasonably sized members. It is important, however, that the overall design still be capable of handling the expected deflections. Story drifts that are too large can result in secondary forces and stresses for which the structure was not designed, as well as increase the damage to the interior and exterior building components, and hinder the means of egress from the building.

Typical means of resisting these forces include the use of moment frames, shear walls, and braced frames. Each of these types of lateral systems can be made up of one of the main structural materials (such as steel or reinforced concrete moment frames; masonry, wood, or reinforced concrete shear walls; or steel or reinforced concrete braced frames). The building configuration and design parameters will have a major effect on which system to choose, and, subsequently, the lateral system chosen will have a major impact on the foundations required to resist the loads.

Moment frames typically are distributed more evenly over the building footprint and have little or no uplift; they also generally have large base moments that can be difficult to resist. In addition, moment frames will tend to have greater lateral deflections than other stiffer systems (such as shear walls or braced frames). Concrete shear walls and steel braced frames are more localized, concentrating not only lateral shear at the base, but also having a high potential for net uplift forces to be resisted. These forces are difficult to resist with some foundation systems, and you should review them extensively before selecting the lateral load-resisting system.

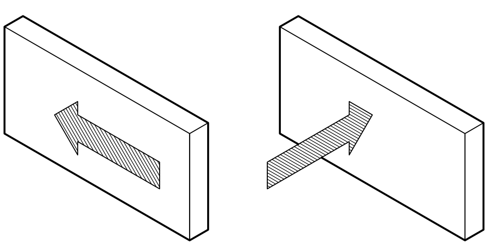
Tall, narrow structures tend to have overturning issues before they will face sliding issues, whereas short structures face sliding problems rather than overturning problems. Seismic motion rocks the building, increasing overturning loads, and can act in any direction. Thus, resistance to overturning is best achieved at a building's perimeter, rather than at its core.

MAIN CAUSES OF FOUNDATION FAILURE
1.75



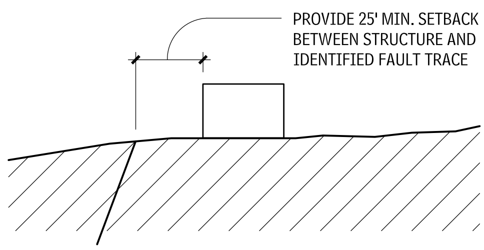
GROUND RUPTURE **GROUND SHAKING** **DIFFERENTIAL SUBSIDENCE** **LIQUEFACTION**

LATERAL FORCE DIAGRAMS
1.76



IN-PLANE **OUT-OF-PLANE**

SURFACE FAULTING
1.78



SITE SECTION

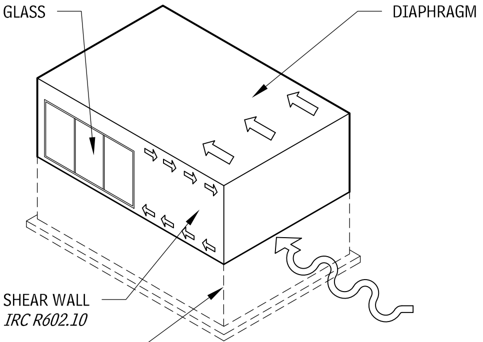
NOTES

1.77 On sloping sites, earthquakes can trigger landslides. Also, alluvium and unconsolidated soils can increase the violence and duration of ground shaking. In areas of young soil deposits, design for greater ground shaking. For example, during the 1989 Loma Prieta earthquake, ground shaking in San Francisco's Marina district, on nonengineered fill, was more than twice as violent and lasted more than twice as long as ground shaking on adjacent bedrock sites.

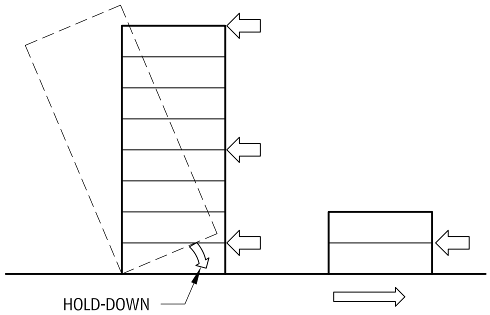
1.78 Within a fault zone, trench to determine the exact location of the fault trace. Development within a fault zone should be restricted to low-density land uses, open space, and other low-occupancy activities.

Contributor:
William W. Stewart, FAIA, Stewart-Schaberg Architects, Clayton, Missouri.

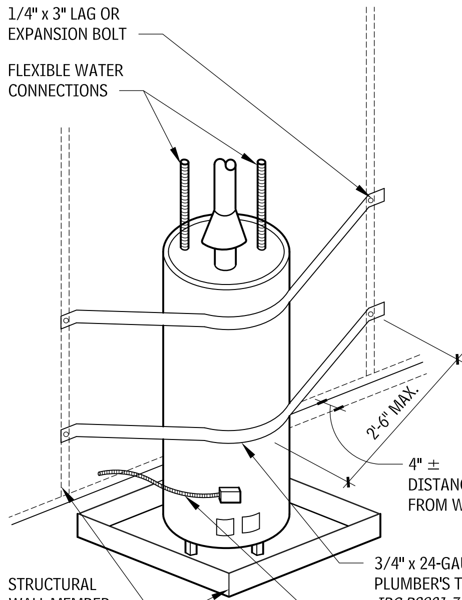
SHEAR WALLS AND DIAPHRAGMS
1.80



OVERTURNING AND SLIDING
1.81



WATER HEATER SEISMIC REINFORCING
1.82



Building foundations must be designed to resist the lateral forces transmitted through the earth, and the forces transmitted from the lateral load-resisting system to the earth. In general, softer soils amplify seismic motion.

COMPONENTS FOR SEISMIC DESIGN

GENERAL GUIDELINES

When detailing architectural and mechanical elements for seismic resistance, the architect's primary concerns are to minimize falling hazards and to maintain a normal egress route. Features such as masonry chimneys and heavy pipes are potential falling hazards. Cabinets and bookcases can block exits if they fall.

Many resources that offer detailed solutions for seismic design only address areas with high seismic activity. However, no single detail is appropriate for all areas. This section is meant to guide architects through the philosophy of seismic design. Readers should use the references listed to develop the right solution for a particular site.

WATER HEATERS

When a water heater overturns, a gas line can rupture. Depending on the level of seismicity, the common solution for residential water heaters is to use a flexible gas connection and/or a simple steel strap wrapped around the tank and securely anchored to a stud or solid wall.

SHELVING AND CABINETS

Shelves and racks can overturn during seismic activity, injuring building occupants or blocking exits. The hazard increases with the occupancy density and the height of the equipment. Fixtures should be bolted onto heavy-gauge studs above their center of gravity.

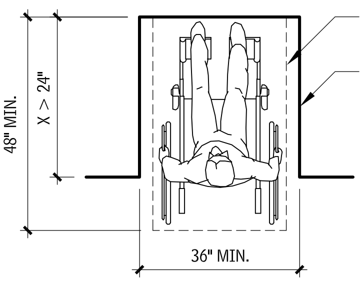
ACCESSIBLE DESIGN

The IRC does not require compliance with any accessibility codes. The designer or home owner may wish to incorporate accessible design strategies from some of the common accessible standards. For the purpose of future adaptability, the designer may want to consider accessible components during the design stage.

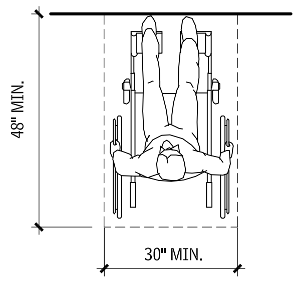
The most common accessibility standards include ANSI A117.1–2004; ADA Standards for Accessible Design, excerpt from 28 CFR Part 36–1994. Many jurisdictions have their own accessibility codes that they have adopted. The U.S. Access Board published ADA-ABA Guidelines in 2004; currently, this document has not been adopted but serves as the baseline for enforceable standards maintained by other federal agencies.

MANEUVERING CLEARANCES

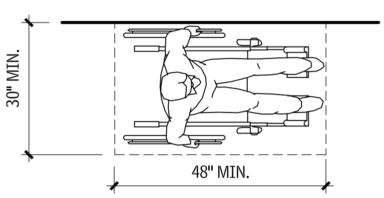
MANEUVERING CLEARANCES
1.83



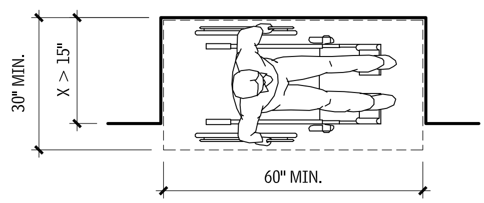
FORWARD APPROACH–ALCOVE



FORWARD



PARALLEL



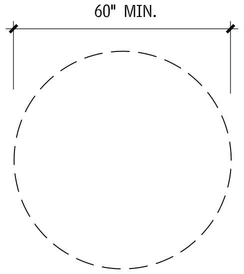
PARALLEL APPROACH–ALCOVE

NOTE

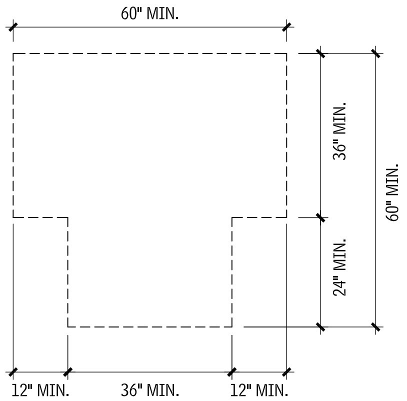
1.82 Fill space between water heater and wall with 2x blocking with cushioned face.

Contributors:
AIA/ACSA Council on Architectural Research. Buildings at Risk: Seismic Design Basics for Practicing Architects.
National Earthquake Hazards Reduction Program (NEHRP). Prestandard and Commentary for the Seismic Rehabilitation of Buildings (FEMA-356).
———. Non-Technical Explanation of the 1994 NEHRP Recommended Provisions (FEMA-99).
William W. Stewart, FAIA, Stewart-Schaberg Architects, Clayton, Missouri.
Scott Maxwell, PE, SE, Adrian, Michigan.

WHEELCHAIR TURNING SPACE
1.84



CIRCULAR

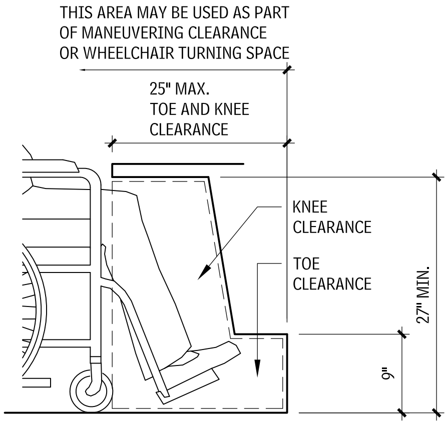


T-SHAPED

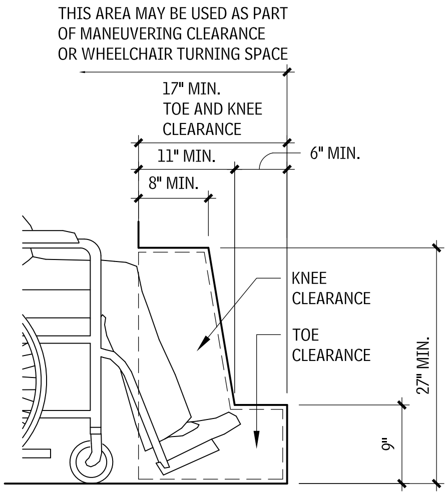
GENERAL NOTES FOR KNEE AND TOE CLEARANCE

- Knee and toe clearance must always be at least 30 in. wide.
- Knee and toe clearance can be included as part of the wheelchair turning space and clear floor space at accessible elements. However, the extent and location of knee and toe clearance can affect the usability of the space.

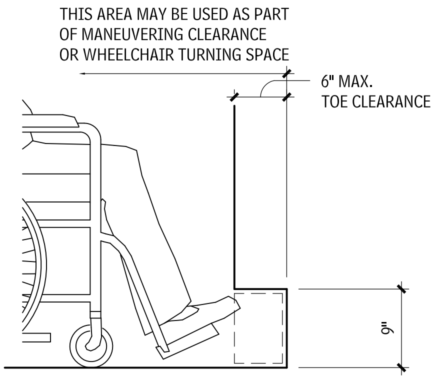
KNEE AND TOE CLEARANCES
1.85



MAX. CLEARANCE



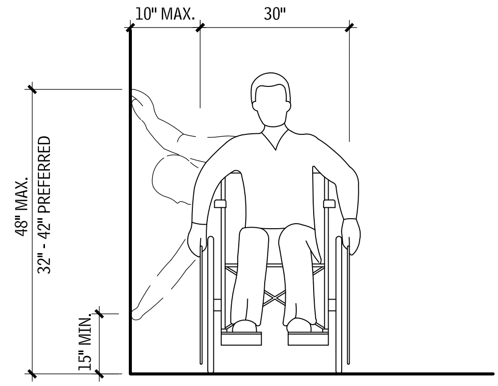
MIN. CLEARANCE



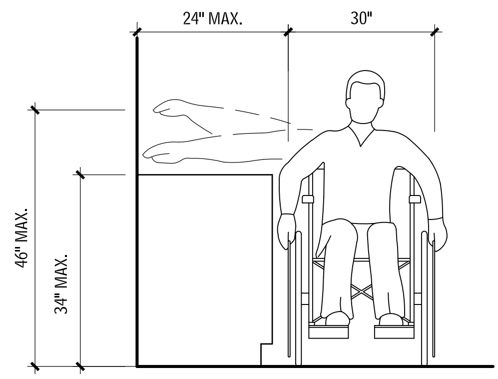
TOE CLEARANCE ONLY

REACH RANGES FOR ACCESSIBILITY

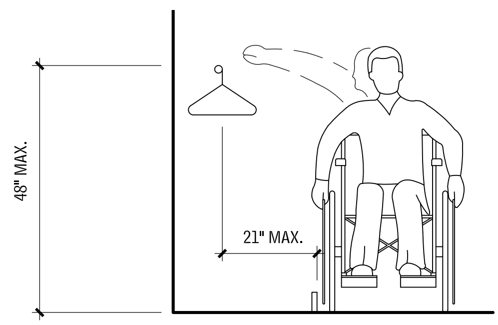
PARALLEL/SIDE REACH LIMITS
1.86



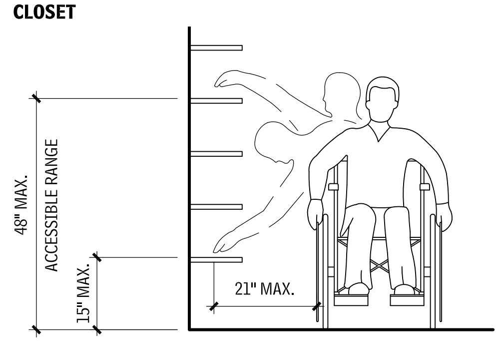
HIGH AND LOW SIDE REACH LIMITS-UNOBSTRUCTED



MAXIMUM SIDE REACH OVER OBSTRUCTION



CLOSET



SHELVES

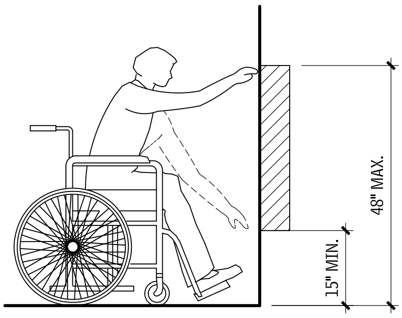
NOTES

1.84 Knee and toe clearance that is included as part of a T-shaped turning space should be provided only at the base of the T or on one arm of the T. In some configurations, the obstruction of part of the T shape may make it impossible for a wheelchair user to maneuver to the desired location.

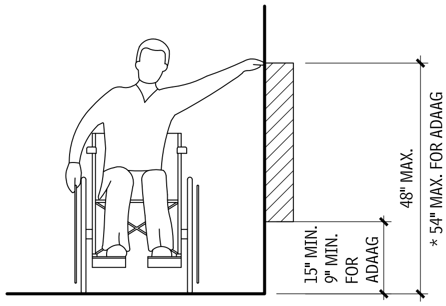
1.85 a. Additional space can be provided beneath the table, desk, or other element, but that space is not considered knee and toe clearance. b. Clearances shown are required at specific accessible elements.

Contributor:
Lawrence G. Perry, AIA, Silver Spring, Maryland.

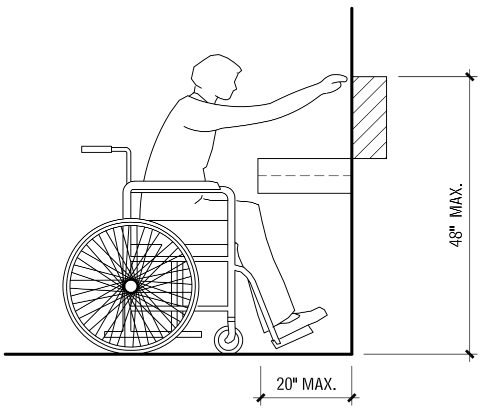
REACH RANGES
1.87



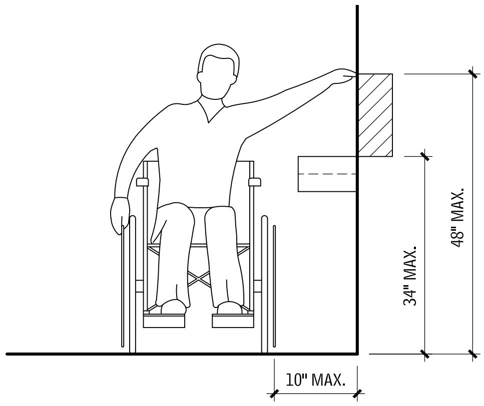
UNOBSTRUCTED FORWARD REACH



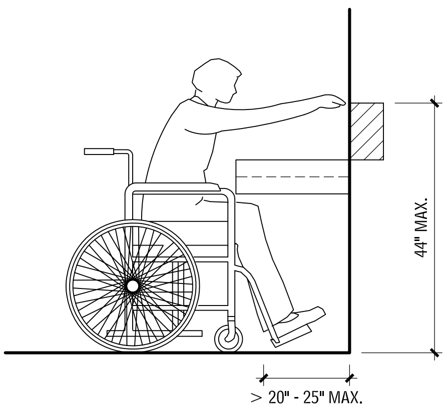
UNOBSTRUCTED SIDE REACH



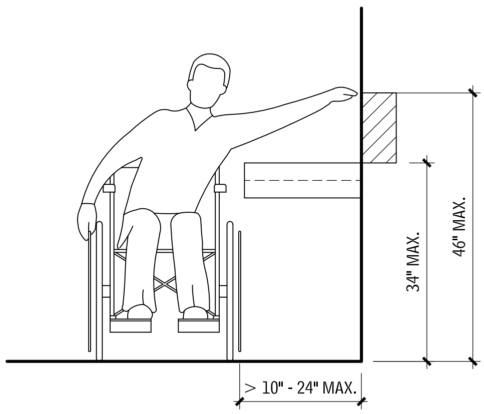
OBSTRUCTED HIGH FORWARD REACH



OBSTRUCTED SIDE REACH



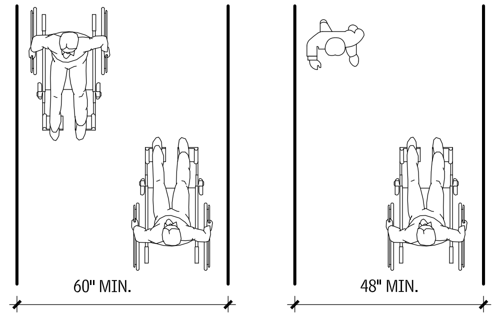
OBSTRUCTED HIGH FORWARD REACH



OBSTRUCTED SIDE REACH

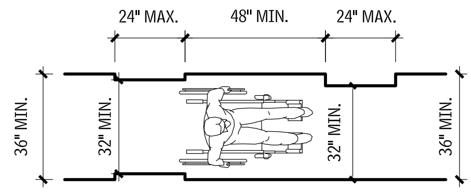
ACCESSIBLE ROUTES AND WALKING SURFACES

CLEAR WIDTH OF AN ACCESSIBLE ROUTE
1.88



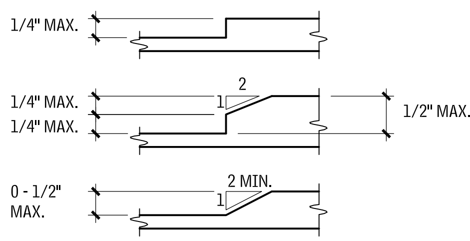
TWO WHEELCHAIRS

ONE WHEELCHAIR AND ONE AMBULATORY PERSON

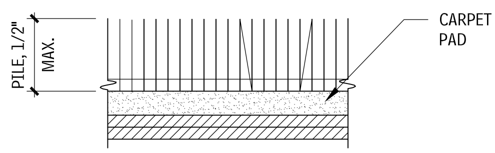


SINGLE WHEELCHAIR

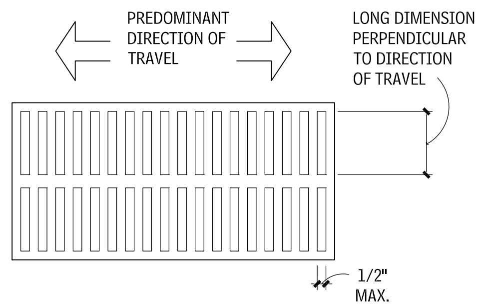
CHANGES IN LEVEL
1.89



FLOOR AND GROUND SURFACES
1.90



CARPET ON FLOOR OR GROUND SURFACES

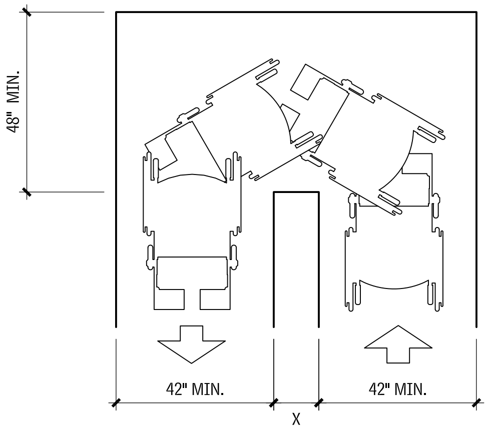


OPENING IN FLOOR OR GROUND SURFACES

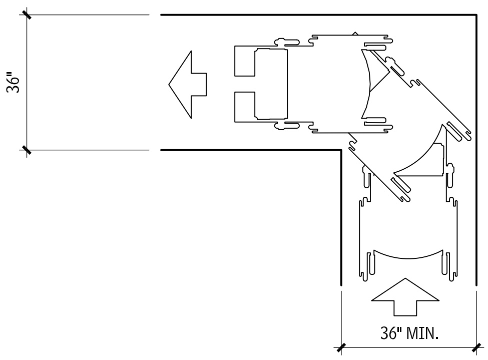
NOTES

1.89 a. Changes in level greater than 1/2 in. must be ramped.
b. Some standards prohibit changes in level in clear floor space, maneuvering clearances, wheelchair turning space, and access aisles.
1.90 a. All surfaces must be firm, stable, and slip resistant.
b. Other openings, such as in wood decking or ornamental gratings, shall be designed so that a 1/2-in.-diameter sphere cannot pass through the opening. The potential for wood shrinkage should be considered.

TURNS
1.91



U-TURN AROUND AN OBSTRUCTION



90° TURN

COMPONENTS OF ACCESSIBLE ROUTES

Accessible routes are permitted to include the following elements: (1) walking surfaces with a slope of less than 1:20, (2) curb ramps, (3) ramps, (4) elevators, and (5) platform (wheelchair) lifts. (The use of lifts in new construction is limited to locations where they are specifically permitted by the applicable regulations. Lifts are generally permitted to be used as part of an accessible route in alterations.)

Each component has specific technical criteria that must be applied for use as part of an accessible route. Consult the applicable code or regulation.

LOCATION OF ACCESSIBLE ROUTES

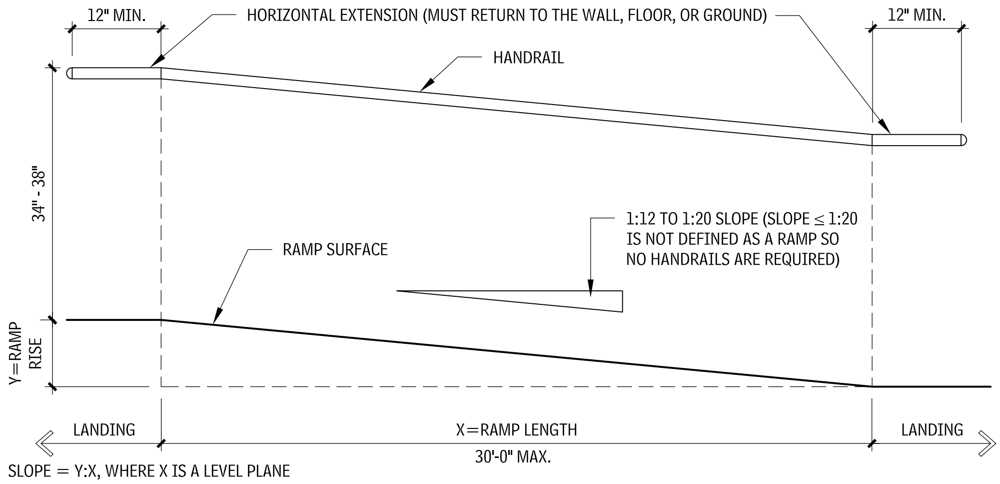
Interior routes. Where an accessible route is required between floor levels and the general circulation path between levels is an interior route, the accessible route should also be an interior route.

Relation to circulation paths. Accessible routes should "coincide with, or be located in the same area as a general circulation path." Avoid making the accessible route a "second class" means of circulation. Consult the applicable regulations for additional specific requirements regarding location of accessible routes.

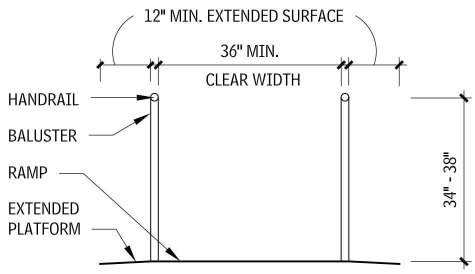
Directional sign. Where the accessible route departs from the general circulation path and is not easily identified, directional signs should be provided as necessary to indicate the accessible route. The signs should be located so that a person does not need to "backtrack."

ACCESSIBLE RAMPS

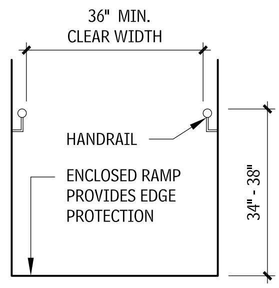
COMPONENTS OF A RAMP
1.92



RAMPS AND LANDINGS—SECTIONS
1.93

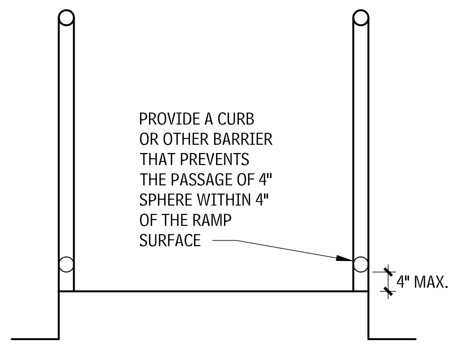


RAMP WITH EXTENDED SURFACE

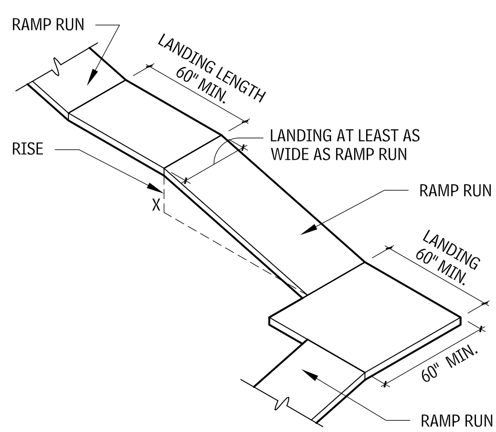


ENCLOSED RAMP

CURB OR BARRIER
1.94



RAMP LANDINGS
1.95



GENERAL NOTES FOR RAMPS

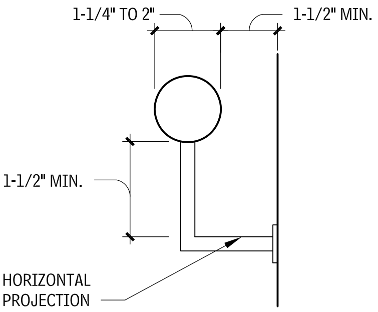
- Accessible ramps must have running slopes of 1:12 or less; surfaces with a running slope greater than 1:20 are considered ramps.
- Design outdoor ramps and approaches so water will not accumulate on surface. Maximum cross slope is 1:48.
- Landings should be level at top and bottom of ramp run and at least as wide as the run leading to it. A 60-by-60-in. landing is required where ramp changes direction. Provide level maneuvering clearances if there is a door at the landing.
- Handrails are required on both sides when rise is greater than 6 in.
- Edge protection is required at ramps and landings that drop off. Refer to local building codes for guardrail requirements.

NOTES

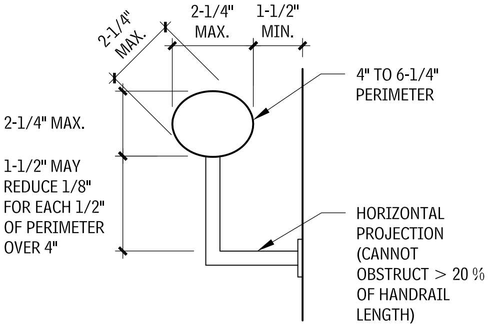
1.91 Dimensions shown apply when X is less than 48 in.
1.95 Handrails and ramp edge protection are not shown in this drawing for clarity.

Contributor:
Lawrence G. Perry, AIA, Silver Spring, Maryland.

HANDRAIL DESIGN
1.96



CIRCULAR

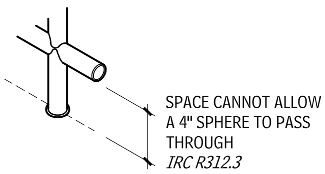


NONCIRCULAR

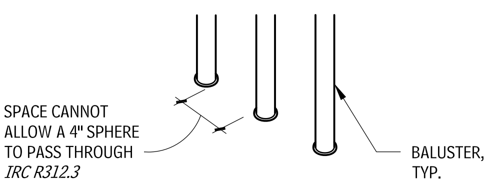
GENERAL NOTES FOR HANDRAILS

- Provide continuous handrails at both sides of ramps and stairs and at the inside handrail of switchback or dogleg ramps and stairs.
- If handrails are not continuous at bottom, top, or landings, provide handrail extensions at ends of handrails to be rounded or returned smoothly to floor, wall, or post.
- Provide handrails of size and configuration shown and gripping surfaces uninterrupted by newel posts or other construction elements; handrails shall not rotate within their fittings.

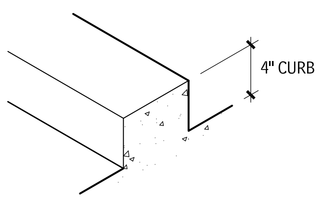
RAMP AND RAMP LANDING EDGE PROTECTION DETAILS
1.97



LOW RAILING



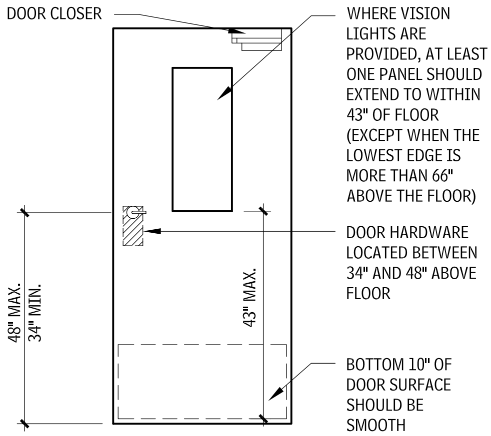
RAILING WITH BALUSTERS



CURB

ACCESSIBLE DOORS

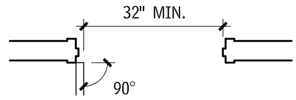
ACCESSIBLE DOOR FEATURES
1.98



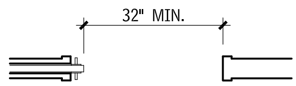
GENERAL NOTES FOR ACCESSIBLE DOORS

- Hardware: Specify hardware that can be operated with one hand, without tight grasping, pinching, or twisting of the wrist.
- Thresholds: Thresholds are typically limited to 1/2 in. maximum height; however, some standards allow a 3/4 in. height for certain sliding doors.
- Opening force: Interior doors (other than fire doors) should be able to be operated with 5 lb of force. Exterior doors and fire doors may be regulated by the authority having jurisdiction.
- For a hinged door, the clear width is measured between the face of the door and the door stop with the door open at a 90° angle.
- For a sliding or folding door, the clear width is measured between the edge of the door and the jamb with the door fully open. Hardware must be accessible with the door in a fully open position.
- Doors in dwelling units covered by FHAG are permitted to have a "nominal" 32-in. clear width. HUD allows a 2-ft-10-in. swing door or a 6-ft exterior sliding door installed in a "typical" manner to satisfy this requirement. ICC/ANSI A117.1-2003 allows a 31-3/4 in. clear width.
- The floor and ground surface within the required maneuvering clearance of a door should not slope more than 1:48 and must be stable, firm, and slip resistant.
- Where doors are recessed more than 8 in. (such as in an alcove or in a very thick wall), the maneuvering clearances for forward approach should be used.
- For doors within dwelling units covered by Fair Housing Accessibility Guidelines (FHAG), maneuvering clearances are not required.
- Doors in dwelling units covered by FHAG are permitted to have a "nominal" 32-in. clear width. HUD allows a 2-ft-10-in. swing door or a 6-ft exterior sliding door installed in a "typical" manner to satisfy this requirement. ICC/ANSI A117.1-2003 allows a 31-3/4 in. clear width.

CLEAR WIDTH OF ACCESSIBLE DOORWAYS
1.99

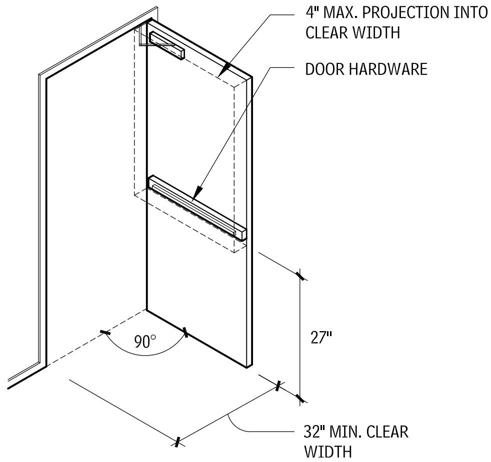


HINGED DOOR



SLIDING OR FOLDING DOOR

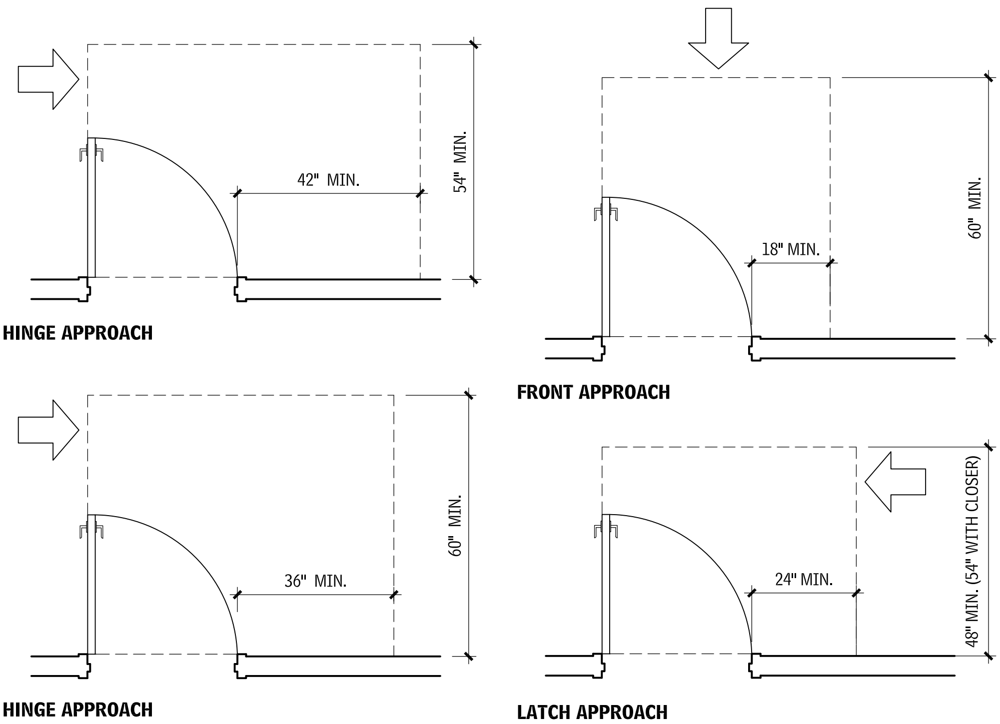
PROJECTIONS INTO CLEAR WIDTH
1.100



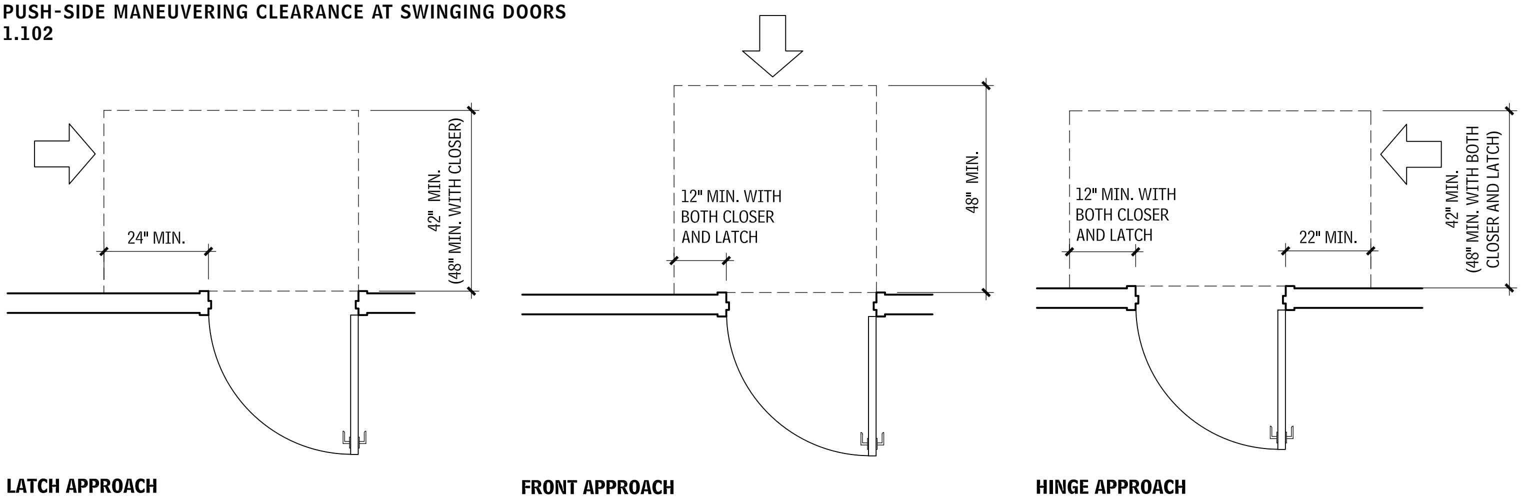
NOTE

1.97 Ramp and ramp landing edge protection can be any configuration that will prevent the passage of a 4-in. sphere, where any portion of the sphere is within 4 in. of the ramp or landing surface.

PULL-SIDE MANEUVERING CLEARANCE AT SWINGING DOORS
1.101

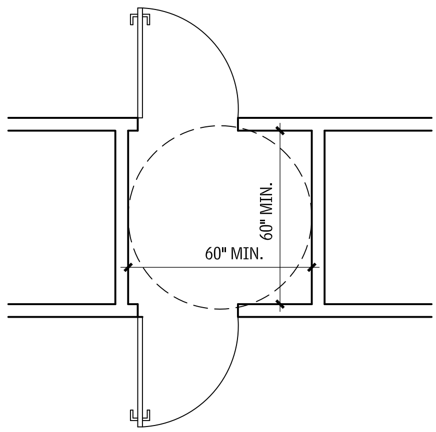


PUSH-SIDE MANEUVERING CLEARANCE AT SWINGING DOORS
1.102

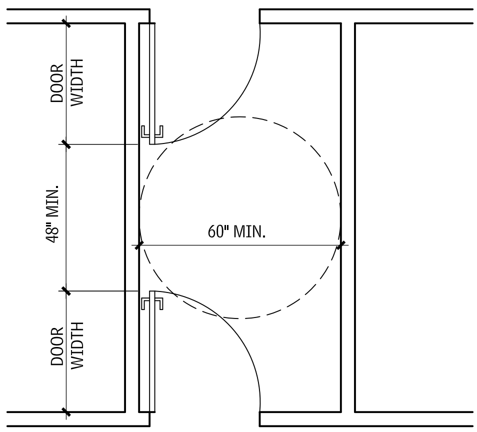


Contributor:
Lawrence G. Perry, AIA, Silver Spring, Maryland.

MANEUVERING CLEARANCE FOR TWO DOORS IN A SERIES
1.103



(A)



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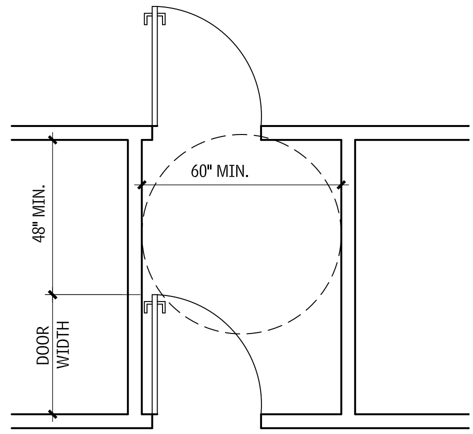
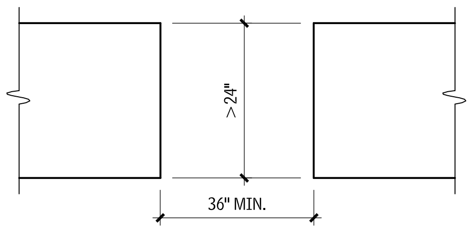
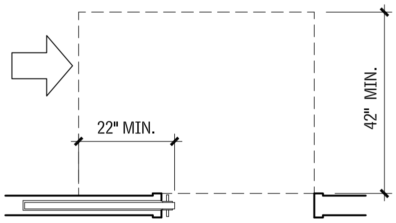


(C)

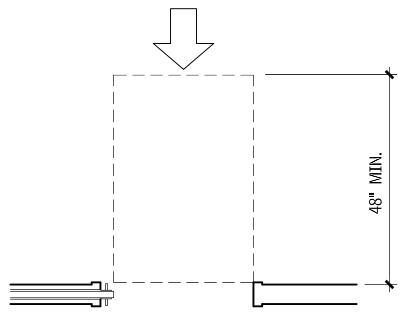


TWO DOORS IN SERIES–ANSI ONLY

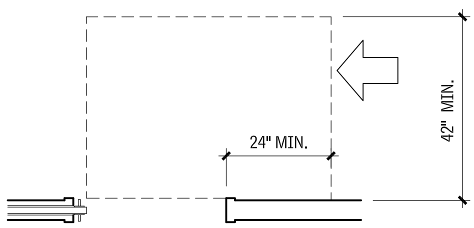
MANEUVERING CLEARANCE AT SLIDING AND FOLDING DOORS
1.104



POCKET OR HINGE APPROACH

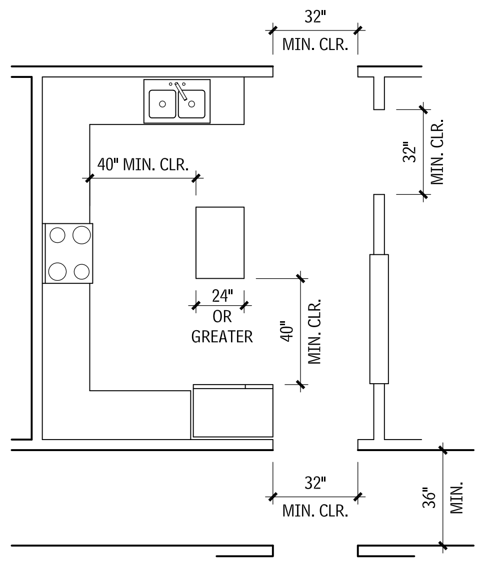


FRONT APPROACH

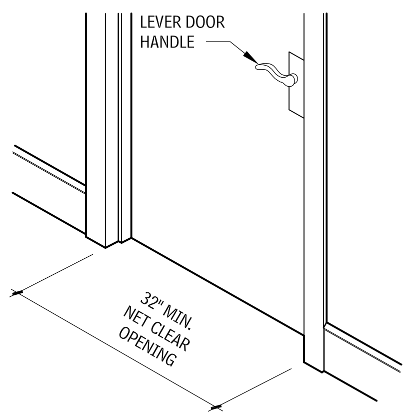


STOP OR LATCH APPROACH

MINIMUM CIRCULATION WIDTHS
1.105



INTERIOR PASSAGE DOOR
1.106



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