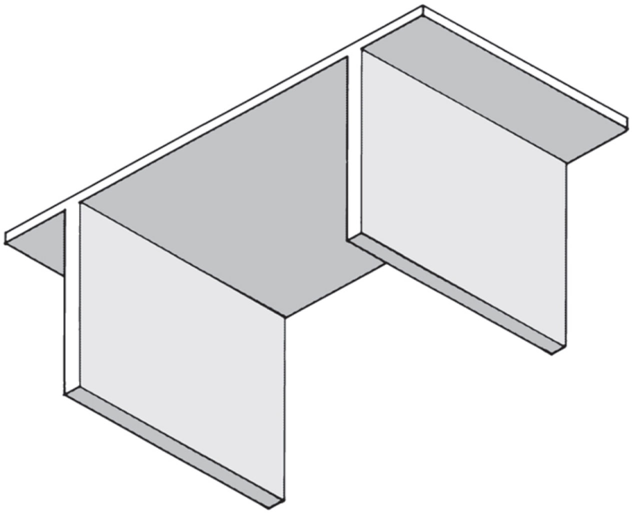
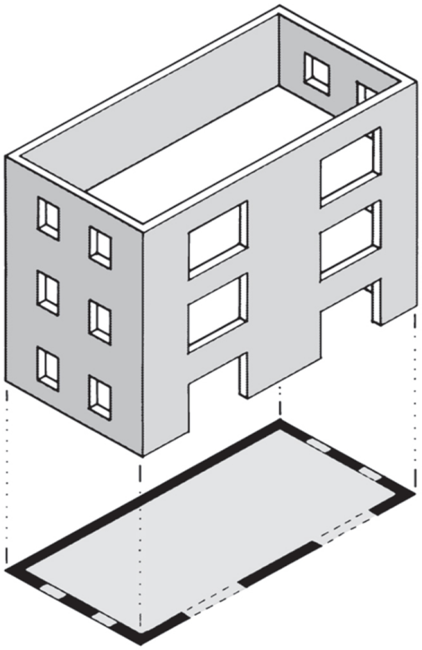


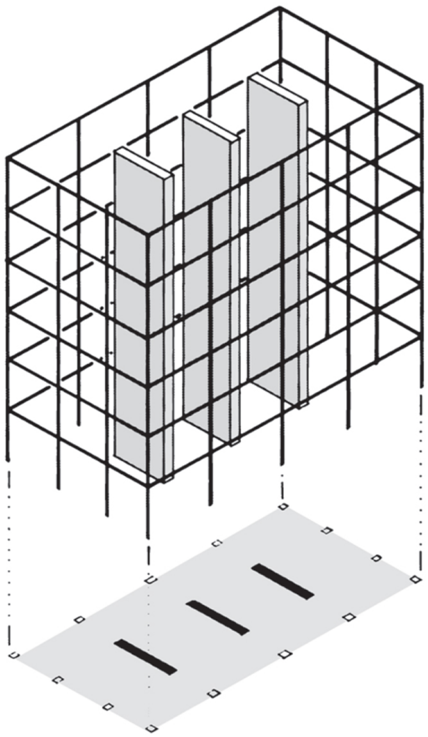


THE ARCHITECT'S STUDIO COMPANION

RULES OF THUMB FOR PRELIMINARY DESIGN

SEVENTH EDITION

JOSEPH IANO • EDWARD ALLEN



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Joseph Iano and Edward Allen

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DISCLAIMER

The information in this book has been interpreted from sources that include building codes, industry standards, manufacturers' literature, engineering reference works, and personal contacts with many individuals. It is presented in good faith, but, although the authors and the publisher have made every reasonable effort to make this book accurate and authoritative, they do not warrant, and assume no liability for, its accuracy or completeness or its fitness for any particular purpose. The user should note especially that this is a book of first approximations, information that is not intended to be used for the final design of any building or structure. It is the responsibility of users to apply their professional knowledge in the use of information contained in this book, to consult original sources for more detailed information, and to seek expert advice as needed, especially in the later stages of the process of designing a building.

This book is printed on acid-free paper. ♾

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This seventh edition of The Architect's Studio Companion
is dedicated to Edward Blair Allen, teacher, mentor,
and dear friend.

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ACKNOWLEDGMENTS

This book has a rich history, and many individuals have helped shape it into what it is today. The idea for *Studio Companion* was hatched by the two authors, sitting on a rock outcropping on a sunny afternoon in Fairmont Park, Philadelphia. Since that time, neither of us ever ceased to look back on that day with gratitude, along with a bit of nostalgia and amazement.

Along the way, numerous editors, publishers, and designers have played important parts in creating and sustaining this book. To name just a few, and in no preferential order: publisher Amanda Miller, executive editor Todd Green, managing editor Amy Odum, former executive editor Margaret Cummins, past editors Paul Drougas and Donna Conte, as well as some of those involved in the publication of this book's first edition, editors Judith R. Joseph and Claire Thompson, and designer Karin Kincheloe.

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Thank you all.

HOW TO USE THIS BOOK

This book is your desktop technical advisor for the earliest stages of building design. It reduces complex engineering information and building regulations to simple formal and spatial approximations that are readily incorporated into design explorations. If you are not familiar with this book, below is a recommended pathway for completing the preliminary design of your building. For more detailed guidance on how to use the information in this book, see the full example beginning on page 481.

Alternatively, information in this book may be accessed in any sequence that fits your particular needs or approach to designing buildings. To jump to any major topic, use the page-edge tabs as a quick index. From within any particular section, you may also follow the many cross references to related information in other parts. In the end, we hope this becomes your personalized handbook, an essential reference for your way of creating buildings.

Step 1: **Determine your building code and Occupancy.** Starting on page 5, determine what model building code to use for your project and what Occupancy classifications apply to the planned activities within your building. These pieces of information are your key to unlocking information throughout other sections of this book.

Step 2: **Find what types of construction are permitted for your project.** Based on the information determined in Step 1, consult the height and area tables that begin on page 393 to determine what code-defined Construction Types are permitted for a building of your size and use.

Step 3: **Complete a preliminary structural design.** Review possible structural systems for your project, beginning on page 24, and consider approaches to the overall configuration of such systems, beginning on page 39. Once you have settled on a system for further study, you can complete a preliminary structural layout and assign approximate sizes to the system's major elements, using the information beginning on page 55.

Step 4: **Consider using daylighting.** Use the information beginning on page 141 to study the potential benefits and formal implications of using daylight illumination in your project.

Step 5: **Plan for mechanical and electrical systems.** Use the information beginning on page 161 for large buildings, or that on page 239 for small buildings, to consider heating and cooling systems that meet the needs of your project. If you wish to incorporate passive heating or cooling systems into your building, refer to the section starting on page 221 as well. Once a viable system, or combination of systems, has been selected, use the information in the following sections to allocate spaces within your building for its HVAC, electrical, plumbing, and other systems.

Step 6: **Determine building code requirements for egress and accessibility.** Use the information that begins on page 267 to lay out the necessary components of your building's exiting system as well as to ensure accessibility for those with disabilities.

Step 7: **Add accommodations for parking.** If provision for parking is a requirement of your project, use the information beginning on page 335 to evaluate both surface and structured parking options.

SECTION

1

DESIGNING WITH BUILDING CODES

1
DESIGNING WITH BUILDING CODES

This section will help you determine which model building code and occupancy classifications to apply to the project you are designing. You will need to know these facts to have full access to the information throughout this book.

BUILDING CODES AND ZONING ORDINANCES

A designer works under complex legal constraints that exert a powerful influence on the form a building may take. Local zoning ordinances control building uses, heights, areas, distances from property lines, and on-site parking capacities. Building codes enacted at the municipal, county, state, or provincial level regulate everything from building heights and areas to the types of interior finish materials that may be used. Further constraints are often imposed by local fire districts, by health and safety regulations pertaining to particular uses, and by regulations governing equal access to public facilities and housing.

Zoning laws and use-specific codes are most often promulgated at the local level and do not lend themselves to simple generalization from one jurisdiction to the next. For this reason, this book does not attempt to address these requirements, and the designer should consult the regulations in effect for guidance in these areas. On the other hand, although building codes are also enforced at local levels, the vast majority of North American building codes are derived from just a few nationally recognized model codes. The use of model codes as the basis for the majority of local building codes results in sufficient standardization that these regulations can be simplified and generalized in a meaningful way. Thus, preliminary guidelines can be provided for incorporating building code requirements into your project.

This book provides building code information based on two model building codes: the International Code Council's *2021 International Building Code* and the National Research Council of Canada, Canadian Commission on Building and Fire Codes' *National Building Code of Canada, 2015*.[1] These two model codes form the basis for the vast majority of building codes enacted by jurisdictions throughout the United States and Canada. This book condenses from these two model codes the provisions that have the most direct effects on building form: height and area limitations, beginning on page 371, and requirements for the design of egress systems and accessible spaces, starting on page 267. Code requirements having to do with the detailed design of structural and mechanical components of buildings are reflected here indirectly through the preliminary sizing charts for structural elements (beginning on page 55) and the rules of thumb for providing space for mechanical and electrical systems (beginning on page 185).

To make use of the information provided in this book, start by selecting the model code appropriate to your project. For projects in the United States, use the International Building Code, and for projects in Canada, use the National Building Code of Canada. Next, consult the appropriate code-specific index that follows, to ascertain the Occupancies for the building you are designing. These two pieces of information—model code and Occupancies—are the keys that will unlock information throughout other sections of this book.

The building code information provided in the following pages is intended only for preliminary purposes. The extent to which this information will accurately reflect the regulations with which any particular project must comply will differ from one locale to another. In some instances, a jurisdiction may adopt one of the model codes included in this book almost verbatim. In many cases, you will find that your project's locale has adopted one of these model codes, but with amendments or alterations to its requirements. And occasionally, you may encounter building code regulations wholly different from either of the model codes included in this book. For these reasons, before becoming too deeply immersed in your design, be sure exactly which codes and regulations govern your project, and verify that the information you use fully and accurately reflects the legal requirements that apply, whether that information comes from this book or other sources.

[1]Close to publication of this text, the delayed 2020 edition of the National Building Code was published. Where possible, information from this new edition of the code has been incorporated.

WHEN TO USE THE INTERNATIONAL BUILDING CODE

If your project is in the United States, use the International Building Code, starting on this page, as the basis for determining preliminary code requirements for your project. If your project is in Canada, use the National Building Code of Canada, starting on page 13. For more information about model building codes and their applicability to your project, see page 5.

OCCUPANCY CLASSIFICATION

Buildings, or portions of buildings, are classified by the activities for which they are used, termed *Occupancies*. These classifications reflect the relative life-safety hazards associated with the activities and occupant characteristics. In general, buildings intended for larger numbers of occupants, for public use, and for inherently hazardous activities are afforded greater levels of protection than those designed for smaller groups, private uses, and nonhazardous activities. Use the information on the following pages to determine which Occupancies most appropriately describe your project.

If your building contains multiple uses, determine the Occupancy classification for each part. Later in this book, you will find more information on how to apply the various code requirements to such mixed-Occupancy facilities; if you would like to learn more about mixed-Occupancy buildings right now, turn to pages 374–377.

GENERAL DESCRIPTION OF OCCUPANCIES

The following table describes each Occupancy according to the International Building Code.

Occupancy	General Description
A ASSEMBLY	Assembly Occupancies include social, recreational, entertainment, and civic gatherings of 50 or more persons. Assembly Occupancy includes five subgroups: A-1: This group includes theaters and halls for the viewing of motion pictures and performing arts, usually with fixed seating. A-2: This group includes food and drink establishments. A-3: This group includes recreational, amusement, and religious worship uses not specifically covered by other Assembly subgroups, including, for example, galleries, churches, community halls, courtrooms, dance halls, indoor sports facilities without fixed seating, lecture halls, libraries, museums, passenger station waiting areas, and the like. A-4: This group includes indoor sports facilities with spectator seating. A-5: This group includes outdoor sports arenas. Gathering spaces less than 750 sq ft (70 m^2) in area or accommodating fewer than 50 persons are treated as Group B, Business Occupancies, or, when located within other Occupancies, as part of the surrounding Occupancy. Assembly spaces located within Group E, Educational facilities, are treated as part of the Group E Occupancy.
B BUSINESS	Business Occupancies include office, professional, and service activities, and storage of related records and accounts. Business Occupancy also includes education facilities past the 12th grade, but does not include retail or wholesale sales, which are classified as Group M Mercantile. Meeting rooms, auditoriums, or other spaces related to business uses but with 50 or more persons are classified as Assembly Occupancy.

(*continued*)

OCCUPANCIES: INTERNATIONAL BUILDING CODE

Occupancy	General Description
E EDUCATIONAL	Educational Occupancies include spaces used for grades K through 12 education and day care facilities for children older than 2½ years of age accommodating six or more children. Auditoriums, gymnasiums, and other assembly areas within Group E facilities are treated as part of the Group E Occupancy. Educational facilities above the 12th grade are classified as Group B Business. Educational rooms and auditoriums within religious facilities, accommodating not more than 99 persons, are considered part of that facility's overall classification, usually Group A-3 Assembly. If they accommodate 100 or more persons, such spaces must be classified separately as Group E. An Educational Occupancy may also include day care for up to 100 children 2½ years and younger when all rooms housing such children are on the ground level and have exit doors leading directly to the exterior.
F FACTORY INDUSTRIAL	Factory Industrial Occupancies include manufacturing, fabricating, finishing, packaging, repairing, and other industrial processes, except those considered especially hazardous, classified as Group H Hazardous, or those classified Group S Storage. Factory Occupancy has two subgroups: F-1 Moderate-Hazard: This group includes manufacturing and industrial processes with moderate fire hazard, such as those involving aircraft, appliances, automobiles, machinery, electronics, plastics, printing, woodworking, and any others not classified as Group F-2. F-2 Low-Hazard: This group includes manufacturing and industrial processes using nonflammable materials, such as those involving nonalcoholic beverages, brick and masonry, ceramics, glass, gypsum, ice, and metal fabrication. Office and storage areas associated with factory facilities are classified as Group B and Group S Occupancies, respectively, unless they are small enough to be treated as accessory to the primary Factory Occupancy (see page 375 for Accessory Occupancies).
H HIGH-HAZARD	High-Hazard Occupancies include manufacturing, processing, and storage of materials with a high potential for health or fire hazard. Hazardous use classifications are specific and detailed about the amounts and types of explosive, flammable, corrosive, or toxic materials involved. If you are considering the design of such a facility, you should consult the appropriate codes from the very outset of your project to determine requirements. High-Hazard Occupancy has five subgroups: H-1: This group includes facilities housing significant quantities of materials that are at risk of explosion or otherwise chemically highly unstable, for example, dynamite. H-2: This group includes facilities housing significant quantities of materials that can act as accelerants in a fire, for example, flammable gases or combustible dust. H-3: This group includes facilities housing significant quantities of materials that readily support combustion or that otherwise present a physical hazard to occupants, such as combustible fibers, consumer fireworks, or oxidizing chemicals. H-4: This group includes facilities housing significant quantities of materials that are corrosive or highly toxic. H-5: This group includes semiconductor fabrication plants and comparable research and development facilities that involve the use of significant quantities of materials specifically identified in the building code as hazardous production materials.
I INSTITUTIONAL	Institutional Occupancies include facilities where occupants cannot fully care for themselves, including residential care, health care, day care, and correctional facilities. Institutional Occupancies are divided into four subgroups: I-1: This group includes 24-hour residential care facilities for 17 or more occupants (not including care staff), for example, group homes, assisted living facilities, convalescent homes, and alcohol and drug rehabilitation centers. Occupants must be capable of responding to an emergency with no more than limited assistance from the facility staff. I-2: This group includes 24-hour medical, psychiatric, and custodial care facilities for six or more persons, in which the occupants are not capable of self-preservation in an emergency, for example, hospitals, nursing homes, and foster care facilities.

(*continued*)

Occupancy	General Description
	I-3: This group includes facilities with six or more occupants (not including staff) who are under restraint or detention, for example, prisons, correctional centers, and reformatories. I-4: This group includes nonmedical custodial day care (less than 24 hours per day) facilities for six or more occupants of any age (not including staff). Offices, dining areas, gifts shops, and other such areas often associated with some Group I facilities should be classified as the appropriate A, B, or M Occupancies unless they are small enough to be treated as accessory to the primary I Occupancy. (See page 375 for Accessory Occupancies.) For more information on the classification of residential and day care facilities, see page 12.
M MERCANTILE	Mercantile Occupancies include the display and sale of retail and wholesale merchandise, as well as areas for the stocking of such goods that include public access.
R RESIDENTIAL	Residential Occupancies include facilities where people live and sleep when not in a supervised setting that would otherwise be classified as Institutional Occupancies. Residential Occupancies are divided into four subgroups: R-1: This group includes hotels, motels, short-term boardinghouses for 11 or more occupants, and other facilities where occupants are primarily transient, typically with stays not exceeding 30 days. R-2: This group includes apartment houses, nontransient boardinghouses, convents, dormitories, nontransient hotels and motels, timeshare properties, and other facilities where occupants are primarily permanent. R-3: This group includes residential facilities not classified as Group I Institutional or other R Occupancies, including one- and two-family residences, and care facilities (both 24-hour and day) for not more than five occupants of any age. Dormitories, fraternities, sororities, and other congregate living facilities where residents share kitchen, dining, and bath areas, with up to 16 permanent residents or 10 transient residents, may also be classified as Group R-3. R-4: This group includes residential care or assisted living facilities for between 6 and 16 occupants above the age of 2½ years. Residents must be capable of responding to an emergency with no more than limited assistance from the facility staff. For more information on the classification of residential and day care facilities, see page 12. Detached one- and two-family dwellings and townhouses, not more than three stories in height, most often are built to comply with the *International Residential Code*, a separate model code written specifically for these building types. Where the activities described in Occupancies R-3 or R-4 are housed in such buildings, these buildings may in many cases be constructed to the requirements of this code. See pages 438 and 440.
S STORAGE	This classification includes storage not classified as H Hazardous, and is divided into two subgroups: S-1 Moderate-Hazard: This group includes storage of books, paper, furniture, grain, lumber, tires, and other materials of moderate fire hazard, as well as motor vehicle repair facilities. S-2 Low-Hazard: This group includes parking garages and buildings for the storage of noncombustible materials. Accessory storage spaces that are less than 100 sq ft (9.3 m^2) in area are classified as part of the primary Occupancy.
U UTILITY AND MISCELLANEOUS	This classification includes agricultural buildings and other structures not included in other Occupancy classifications, such as carports, private garages, greenhouses, livestock shelters, retaining walls, sheds, stables, tanks, towers, and other miscellaneous uses.

OCCUPANCIES: INTERNATIONAL BUILDING CODE

INDEX OF OCCUPANCIES

You may use the following detailed list of building uses to determine the Occupancy classifications for your project. If the specific use for your project is not listed, choose the most similar use based on comparisons of the number and density of occupants, nature of the activity, and any associated fire- or life-safety risks.

WHERE DO I GO FROM HERE?

Once you have determined the building code Occupancy classifications for your project, you can use this information throughout the other sections of this book. If you are unsure of where to go next, see How to Use This Book, page xi, for suggestions on how to proceed.

Building Use	Occupancy
Agricultural buildings, barns, livestock shelters	U
Aircraft hangars, accessory to one- or two-family residences	U
Aircraft hangars, storage and repair	S-1
Aircraft manufacturing	F-1
Airport traffic control towers	B
Alcohol and drug centers, 24-hour care	I-1; see also Institutional and Residential Care Occupancies, p. 12
Amusement arcades	A-3
Amusement park structures	A-5
Animal hospitals, kennels, pounds	B
Apartment houses	R-2
Art galleries	A-3 or B, depending on the number of occupants
Assisted living	I-1; see also Institutional and Residential Care Occupancies, p. 12
Auditoriums	A-3
Auditoriums, part of Group E Educational facilities	E
Banks	B
Banquet halls	A-2
Barber and beauty shops	B
Barns	U
Bleachers, outdoors	A-5
Boardinghouses, not transient	R-2, or R-3 with 16 or fewer occupants
Boardinghouses, transient	R-1, or R-3 with 10 or fewer occupants
Boardinghouses, with rented guest rooms in a single-family dwelling	See Lodging houses
Bowling alleys	A-3
Business offices	B
Car washes	B
Care facilities, 24-hour	See Institutional and Residential Care Occupancies, p. 12
Carports	U
Child care, 24-hour, 6 or more children 2½ years of age or less	I-2; see also Institutional and Residential Care Occupancies, p. 12
Child care, day, 6 or more children 2½ years of age or less	I-4; see also Institutional and Residential Care Occupancies, p. 12
Churches	See Places of religious worship
Civic administration	B
Clinics, outpatient	B
Community halls	A-3
Concert halls	A-2
Congregate living facilities combining individual sleeping units with shared dining, bathing, and recreation (such as dormitories, fraternities, sororities, and convents), 10 or fewer transient residents	R-3
Congregate living, 11 or more transient residents	R-1
Congregate living facilities, 16 or fewer permanent residents	R-3
Congregate living facilities, 17 or more permanent residents	R-2
Convalescent facilities, 24-hour	I-1; see also Institutional and Residential Care Occupancies, p. 12
Convents	See Congregate living facilities

(*continued*)

Building Use	Occupancy
Correctional centers	I-3
Courtrooms	A-3
Dance halls	A-3
Day care, 5 or fewer occupants	R-3; see also Institutional and Residential Care Occupancies, p. 12
Day care, 6 or more occupants	I-4; see also Institutional and Residential Care Occupancies, p. 12
Day surgery centers	B
Department stores	M
Detention centers	I-3
Detoxification facilities, 24-hour	I-2; see also Institutional and Residential Care Occupancies, p. 12
Doctors' offices	B
Drugstores	M
Dry boat storage	S-2
Dry cleaners and laundries	B
Educational facilities, above the 12th grade	B
Educational facilities, K through 12	E
Educational rooms in places of religious worship	Same Occupancy as the main facility, usually A-3
Electronic data processing	B
Exhibition halls	A-3
Factories	F-1, F-2, or H, depending on the hazard
Fences, more than 7 ft (2.1 m) high	U
Fire and police stations	B
Food processing	See Kitchens
Fraternities	See Congregate living
Funeral parlors	A-3
Grandstands, outdoors	A-5
Greenhouses	U
Group homes	I-1; see also Institutional and Residential Care Occupancies, p. 12
Grow houses, marijuana	F-1
Gymnasiums	A-3
Halfway houses, 17 or more persons	I-1; see also Institutional and Residential Care Occupancies, p. 12
Hazardous materials processing and storage	H-1 through H-5; consult the code for more information

Building Use	Occupancy
Health care, ambulatory (outpatient), less than 24-hour	B
Homes, single- or two-family	See International Residential Code, p. 438
Hospitals	I-2
Hotels	R-1
Jails	I-3
Kitchens, part of restaurants or dining facilities	A-2
Kitchens, not part of a restaurant or dining facility	F-1 if more than 2500 sq ft (232 m^2) in area, otherwise B
Laboratories, testing and research	B
Lecture halls	A-3
Libraries	A-3
Lodging houses, with not more than five rented guest rooms in a single-family dwelling	R-3
Markets	M
Martial arts studios	B
Medical care, 24-hour	I-2
Monasteries	See Congregate living
Mosques	See Places of religious worship
Motels	R-1
Motion picture theaters	A-1
Motor vehicle repair	S-1
Motor vehicle service stations	M
Motor vehicle showrooms	B
Museums	A-3
Nightclubs	A-2
Nursing homes	I-2
Offices	B
Outpatient clinics	B
Parking garages, private	U
Parking garages, public	S-2
Passenger station waiting areas	A-3
Places of religious worship, including related public areas, gathering spaces, educational, and child care areas	A-3
Places of religious worship, business areas	B
Pool and billiard halls	A-3
Post offices	B
Prisons	I-3
Professional services	B

(*continued*)

OCCUPANCIES: INTERNATIONAL BUILDING CODE

Building Use	Occupancy
Radio and television stations, with audience facilities	A-1
Radio and television stations, without audience facilities	B
Reformatories	I-3
Rehabilitation facilities	I-1; see also Institutional and Residential Care Occupancies, p. 12
Religious facilities	See Places of religious worship
Residential care	See Institutional and Residential Care Occupancies, p. 12
Restaurants	A-2
Retail stores	M
Retaining walls	U
Sales rooms	M
Sheds	U
Skating rinks with spectator seating, indoor	A-4
Sleep clinics	B
Sororities	See Congregate living
Sports arenas, indoor	A-4
Stadiums, outdoors	A-5
Storage	S-1, S-2, or H, depending on the hazard
Swimming pools, indoor, with spectator seating	A-4
Swimming pools, indoor, without spectator seating	A-3
Tanks	U
Taverns and bars	A-2
Telephone exchanges	B
Tennis courts, indoors, with spectator seating	A-4
Tennis courts, indoors, without spectator seating	A-3
Theaters	A-1
Tower structures, nonoccupied	U
Training facilities, nonacademic	B
Wholesale stores	M

INSTITUTIONAL AND RESIDENTIAL CARE OCCUPANCIES

In the International Building Code, day care and residential care facilities are assigned to Occupancies based on the ages of the individuals under care, the number of individuals receiving care, the duration of the care, and the extent to which occupants can fend for themselves in the event of a building emergency. Use the following table to determine the most appropriate Occupancy classification for such uses. Other related classifications, not listed in the table, include the following:

- Day facilities for able-bodied adults who do not require personal care and are capable of responding to emergencies without assistance are classified as either Occupancy A-3 or B, depending on the number of occupants. This includes, for example, community centers, YMCAs, and other similar facilities.
- Doctors' offices, outpatient clinics, and similar facilities where patient stays do not exceed 24 hours are classified as Occupancy B.
- Facilities that provide medical care extending beyond a 24-hour stay, and where residents require physical assistance in the case of a building emergency, are classified as Occupancy I-2. This includes, for example, hospitals, nursing homes, detoxification facilities, and child care facilities with stays extending beyond 24 hours.

Age of Occupants	**Day Care (less than 24-hour)**		**24-Hour Care**		
	1–5 occupants	6 or more occupants	1–5 occupants	6–16 occupants	17 or more occupants
2½ years or less	R-3	I-4[a]	R-3	I-2	I-2
Over 2½ years, not capable of self-preservation	R-3	I-4[a]	R-3	I-2	I-2
Over 2½ years and capable of self-preservation	Accessory to primary Occupancy, or R-3	E for children up to the 12th grade I-4 for adults[a]	R-3	R-4	I-1

Numbers of occupants includes only individuals receiving care, and excludes staff and care providers.

[a]Day Care Exceptions:

Day care occurring during worship activities within a religious facility may be classified with the primary Occupancy, usually A-3.

Up to 100 children 2½ years or less in age may receive day care in a Group E Occupancy when all such children are located in rooms on the ground floor, with exit doors in each room leading directly to the exterior.

Day care facilities for adults above the 12th grade and capable of responding to an emergency without assistance may also be classified as Group R-3, if the facility meets other code requirements for this Occupancy.

OCCUPANCIES: NATIONAL BUILDING CODE OF CANADA

WHEN TO USE THE NATIONAL BUILDING CODE OF CANADA

If your project is in Canada, use the National Building Code of Canada, starting on this page, as the basis for determining preliminary code requirements for your project. If your project is in the United States, use the International Building Code, starting on page 6. For more information about model building codes and their applicability to your project, see page 5.

OCCUPANCIES

Buildings, or portions of buildings, are classified by the primary activities for which they are used, termed *Major Occupancies*. These classifications reflect the relative life-safety hazard associated with the activities and occupant characteristics. In general, buildings intended for larger numbers of occupants, for public use, and for inherently hazardous activities are afforded greater levels of protection than those designed for smaller groups, private uses, and nonhazardous activities. Use the information on the following pages to determine what Occupancy classifications most appropriately describe your project.

If your building contains multiple uses, determine the occupancy for each part. Later in this book you will find more detailed information on how to apply the various code requirements to such mixed-occupancy facilities; if you would like to learn more about mixed-use buildings right now, turn to pages 374–377.

GENERAL DESCRIPTION OF OCCUPANCIES

The following table describes each Occupancy according to the National Building Code of Canada.

Occupancy	General Description
A ASSEMBLY	Assembly Occupancy includes social, recreational, and civic gatherings, and includes four subdivisions: A-1: This division includes facilities for the public production and viewing of the performing arts, such as motion picture theaters, performing arts halls and theaters, and broadcast studios with viewing audiences. A-2: This division includes a broad range of Assembly-type uses not specifically falling under other Assembly subdivisions, for example, auditoriums, churches, community halls, courtrooms, dance halls, gymnasiums, lecture halls, libraries, museums, passenger stations and depots, nonresidential schools and colleges, and other public gathering facilities. A-3: This division includes indoor arena-type facilities, such as swimming pools (with or without spectator seating), arenas, and rinks. A-4: This division includes open-air Assembly facilities such as outdoor sports stadiums, amusement park structures, and other facilities with outdoor bleachers or grandstands.
B CARE, TREATMENT, OR DETENTION	Care, Treatment, or Detention Occupancy includes facilities where occupants cannot fully care for themselves, and includes three subdivisions: B-1: This division includes Detention Occupancies in which occupants are under restraint or incapable of self-preservation due to security measures, such as prisons and jails, as well as psychiatric hospitals, reformatories, and other care facilities with detention quarters. B-2: This division includes medical or health-related treatment Occupancies that do not include detention, such as hospitals, infirmaries, and psychiatric hospitals, as well as convalescent homes, hospices, nursing homes, respite centers, and other similar facilities in which medical treatment is provided. B-3: This division includes facilities providing cognitive, behavioral, or physical care for greater than 24 hours, without medical treatment or detention, such as assisted living, children's custodial homes, convalescent homes, group homes, nursing homes, reformatories, and respite centers.
C RESIDENTIAL	Residential Occupancy includes all kinds of residential uses not classified as Care or Detention, for example, apartments, boardinghouses, residential colleges and schools, hotels, single-family houses, and the like.

(*continued*)

OCCUPANCIES: NATIONAL BUILDING CODE OF CANADA

Occupancy	General Description
D BUSINESS AND PERSONAL SERVICES	Business and Personal Services Occupancy includes office, professional, and service activities, such as banks, beauty parlors, doctors' offices, business offices, police stations (without detention), and radio stations. This Occupancy does not include retail or wholesale sales, which are classified as Occupancy E.
E MERCANTILE	Mercantile Occupancies include the display and sale of retail and wholesale merchandise and the related stocking of such goods.
F INDUSTRIAL	Industrial Occupancies include manufacturing and industrial facilities, and include three subdivisions: F-1: This division includes high-hazard manufacturing processes, such as those involving highly flammable or hazardous substances. F-2: This division includes medium-hazard manufacturing processes and materials. F-3: This division includes low-hazard manufacturing processes and materials.

OCCUPANCIES: NATIONAL BUILDING CODE OF CANADA

INDEX OF OCCUPANCIES

You may also use the following index of uses to determine the Occupancy classification(s) for your project. If the specific use for your project is not listed, choose the most similar use based on comparisons of the number and density of occupants, nature of the activity, and any associated fire- or life-safety risks.

WHERE DO I GO FROM HERE?

Once you have determined the building code Occupancy classifications for your project, you can use this information throughout the other sections of this book. If you are unsure of where to go next, see page xi, "How to Use This Book," for suggestions on how to proceed.

Building Use	Occupancy
Aircraft hangars	F-2
Aircraft hangars (light-aircraft, storage only)	F-3
Amusement park structures	A-4
Apartments	C
Appliance rental and service establishments, small	D
Arenas, indoor, including when used for occasional trade shows or exhibitions	A-3
Art galleries	A-2
Assisted living facilities	B-3
Auditoriums	A-2
Banks	D
Barber shops	D
Beauty shops	D
Beverage establishments	A-2
Bleachers, open air	A-4
Boarding houses	C
Bowling alleys	A-2
Box factories	F-2
Candy manufacturing plants	F-2
Care facilities, with medical treatment	B-2
Care facilities, without medical treatment	B-3
Cereal mills	F-1
Chemical plants	F-1
Children's custodial homes	B-3
Children's custodial homes, with not more than 10 ambulatory occupants living as a single housekeeping unit	C

Building Use	Occupancy
Clubs, nonresidential	A-2
Cold storage	F-2
Colleges, nonresidential	A-2
Colleges, residential	C
Community halls	A-2
Concert halls	A-1
Convalescent centers, with medical treatment	B-2
Convalescent centers, with not more than 10 ambulatory occupants living as a single housekeeping unit	C
Convalescent centers, without medical treatment	B-3
Convents	C
Courtrooms	A-2
Creameries	F-3
Dance halls	A-2
Dental offices	D
Department stores	E
Distilleries	F-1
Dormitories	C
Dry cleaning establishments, not using flammable or explosive solvents or cleaners	F-2
Dry cleaning establishments, self-service	D
Dry cleaning plants, other	F-1
Electrical stations	F-2
Exhibition halls, mercantile	E
Exhibition halls, other than mercantile	A-2

(*continued*)

OCCUPANCIES: NATIONAL BUILDING CODE OF CANADA

Building Use	Occupancy
Factories	F-1, F-2, F-3, depending on hazard
Farm buildings	Nonresidential, agricultural-use buildings are regulated by the National Farm Building Code of Canada, not included in this publication
Feed mills	F-1
Flour mills	F-1
Freight depots	F-2
Garages, repair	F-2
Grain elevators	F-1
Grandstands, open air	A-4
Group homes	B-3
Gymnasiums	A-2
Hairdressing shops	D
Helicopter rooftop landing areas	F-2
Hospices, with medical treatment	B-2
Hospices, without medical treatment	B-3
Hospitals	B-2
Hotels	C
Houses	C
Industrial salesrooms	F-1, F-2, or F-3, depending on hazard
Industrial sample display rooms	F-3
Infirmaries	B-2
Jails	B-1
Laboratories	F-1, F-2, or F-3, depending on hazard
Lacquer factories	F-1
Laundries, except self-service	F-2
Laundries, self-service	D
Lecture halls	A-2
Libraries	A-2
Lodging houses	C
Markets	E
Mattress factories	F-1 or F-2, depending on hazard
Medical offices	D
Monasteries	C
Motels	C
Motion picture theaters	A-1
Museums	A-2
Nursing homes, with medical treatment	B-2
Nursing homes, without medical treatment	B-3
Opera houses	A-1
Paint, varnish factories	F-1
Paper-recycling plants	F-1
Parking garages, enclosed or open	F-3
Passenger stations, depots	A-2
Penitentiaries	B-1
Places of religious worship	A-2
Planing mills	F-2
Police stations, not more than one story in height and 600 m^2 (6460 ft^2) in building area	B-2
Police stations, with detention quarters	B-1
Police stations, without detention facilities	D
Power plants	F-3
Printing plants	F-2
Prisons	B-1
Psychiatric hospitals, with detention quarters	B-1
Psychiatric hospitals, with medical treatment	B-2
Radio stations	D
Recreational piers	A-2
Reformatories, with detention quarters	B-1
Reformatories, without medical treatment	B-3
Rehabilitation centers, with medical treatment	B-2
Rehabilitation centers, without medical treatment	B-3
Respite centers, with medical treatment	B-2
Respite centers, without medical treatment	B-3
Restaurants	A-2
Reviewing stands, open air	A-4
Rinks, indoor	A-3
Rubber-processing plants	F-1
Schools, nonresidential	A-2
Schools, residential	C

(*continued*)

Building Use	Occupancy
Service stations	F-2
Shops	E
Spray-painting operations	F-1
Stadiums, open air	A-4
Storage, baled combustible fibers	F-2
Storage, bulk, flammable liquids	F-1
Storage, bulk, hazardous chemicals	F-1
Storage, other	F-1, F-2, or F-3, depending on hazard
Stores	E
Supermarkets	E
Swimming pools, indoor, with or without spectator seating	A-3
Television studios, admitting a viewing audience	A-1
Television studios, with viewing audience	D
Television studios, without a viewing audience	F-2
Theaters, performance	A-1
Tool rental and service establishments, small	D
Warehouses	F-1, F-2, or F-3, depending on hazard
Wholesale rooms	F-2
Woodworking shops	F-2
Workshops	F-2 or F-3, depending on hazard

SECTION

2

DESIGNING THE STRUCTURE

1 SELECTING THE STRUCTURAL SYSTEM

This section will help you select a structural system for the preliminary design of your building.

BUILDING CODE CRITERIA FOR THE SELECTION OF STRUCTURAL SYSTEMS

The first step in selecting a building's structural system is to determine which systems are permitted by the building code in effect for your project. When working directly in the codes themselves, you must consult numerous provisions that prescribe the maximum height and floor area to which a building may be built, with consideration of the Occupancies within the building, distinctions between various code-defined Construction Types, the presence of fire sprinklers, and other factors. To streamline this process, simplified tables of area and height limitations for each model code are provided in this book. To use these tables, proceed as follows:

■ If you have not already done so, first find the model code that applies to your building and the Occupancy classifications into which it falls (pages 16–17).

■ Refer to the Height and Areas Tables, beginning on page 393, and locate the one or more tables that apply to your building.

■ From the Height and Area Tables, find the allowable Construction Types for the size of the building required for your project.

■ To learn more about each acceptable Construction Type, see pages 382–392.

Knowing which Construction Types are permitted for your project will help you in making preliminary selections of structural systems on the pages that follow in this section.

If you wish to create a building with a highly irregular form:

Choose systems with simple floor and roof framing that are fabricated mostly on-site, such as:

- Wood light frame (pages 57–65)
- Masonry construction with either concrete slab or light wood floor framing (pages 81–92)
- Lightweight steel framing (pages 93–97)
- Sitecast concrete using any slab system without beams or ribs (pages 109–113, 116–117, 120–123)

If you wish to leave the structure exposed while retaining a high fire-resistance rating:

Choose structural systems that are inherently resistant to fire and heat, including:

- Heavy timber construction (pages 57, 66–73, 76–79)
- Cross-laminated timber (pages 74–75)
- Mill construction (page 81)
- All concrete systems (although ribbed systems may require added thickness in the ribs or slab or applied fireproofing) (pages 109–137)

For further information on the fire resistance of various structural systems and the uses for which they are permitted, see pages 382–385.

If you wish to allow column placements that deviate from a regular grid:

Use systems that do not include beams or joists in the floor and roof structure, such as:

- Sitecast concrete two-way flat plate or flat slab (pages 120–123)

Or, consider a framed system that is flexible in its span and configuration capabilities, such as:

- Steel frame (pages 382–385)

If you wish to minimize floor thickness to reduce total building height or to reduce floor spandrel depth on the building façade:

Use the thinnest floor slab systems without ribs, such as:

- Cross-laminated timber (pages 74–75)
- Posttensioned one-way solid slab (pages 116–117)
- Sitecast concrete two-way flat plate or flat slab, especially when posttensioned (pages 120–123)
- Precast prestressed hollow-core or solid slab (pages 134–135)

DESIGN CRITERIA FOR THE SELECTION OF STRUCTURAL SYSTEMS

If you wish to minimize the area occupied by columns or bearing walls:

Consider long-span structural systems, such as:

- Engineered wood beams (pages 72–73)
- Heavy wood trusses (pages 76–77)
- Glue-laminated wood arches (pages 78–79)
- Steel frame (pages 98–105)
- Open-web steel joists (page 106)
- Single-story rigid steel frame (page 107)
- Steel trusses (page 108)
- Sitecast concrete one-way joist or waffle slab, particularly when posttensioned (pages 118–119, 124–125)
- Precast concrete single or double tees (pages 136–137)

You may also wish to consider other long-span systems, such as specially fabricated steel beams, suspended systems, arches, vaults, and shells.

If you wish to allow for changes to the building over time:

Consider short-span systems with one-way slabs that permit easy structural modification, such as:

- Wood light frame (pages 57–65)
- Heavy timber construction (pages 57, 66–73)
- Lightweight or conventional steel framing (pages 93–107)
- Sitecast concrete one-way solid slab or one-way joist construction, excluding posttensioned (pages 116–119)

If you wish to permit construction under adverse weather conditions:

Select a system that does not depend on on-site chemical processes (such as the curing of concrete or mortar) and that can be erected quickly, such as:

- Any wood system (pages 57–79) (Cross-laminated timber may require protection from precipitation to prevent excessive wetting.)
- Any steel system (pages 93–108)
- Precast concrete systems, particularly those that minimize the use of sitecast concrete toppings and grouting (pages 127–137)

If you wish to minimize site disturbance during construction:

Choose column and beam systems supported on point footings, thereby minimizing excavation, such as:

- Heavy timber construction (pages 57, 66–73)
- Steel frame (pages 98–105)

Choose long-span systems that minimize bearing elements, such as:

- Engineered wood beams (pages 72–73)
- Heavy wood trusses (pages 76–77)
- Glue-laminated wood arches (pages 78–79)
- Open-web steel joists (page 106)
- Steel trusses (page 108)

Choose systems that rely on a high degree of off-site prefabrication to minimize construction activities on-site, such as:

- Cross-laminated timber (pages 74–75)
- Single-story rigid frame (Page 107)
- Any precast concrete system (pages 127–137)

If you wish to minimize off-site fabrication time:	Consider systems in which the building is constructed on-site from easily formed, relatively unprocessed materials, such as: Wood light frame (pages 57–65) Any masonry system (pages 81–92) Lightweight steel framing (pages 93–97) Any sitecast concrete system (pages 109–125)
If you wish to minimize on-site erection time:	Consider systems using highly preprocessed, prefabricated, or modular components, such as: Heavy timber construction (pages 57, 66–73, 76–79) Cross-laminated timber (pages 57, 74–75) Steel frame, particularly with shear connections (pages 93, 98–106) Single-story rigid steel frame (Page 107) Steel trusses (Page 108) Any precast concrete system (pages 127–137)
If you wish to minimize construction time for a one- or two-story building:	Consider systems that are lightweight and easy to form, or prefabricated and easy to assemble, such as: Wood light frame (pages 57–65) Heavy timber construction (pages 57, 74–75) Lightweight steel framing (pages 93–97) Steel frame (pages 93, 98–106) Open-web steel joists (Page 106) Single-story rigid steel frame (Page 107)
If you wish to minimize construction time for a 4- to 20-story building:	Choose from the following systems: Cross-laminated timber (pages 74–75) Steel frame (pages 93, 98–106) Precast concrete (pages 127–137) Once the structural components for any of these systems are prefabricated, on-site erection proceeds quickly. Sitecast concrete one-way slab (pages 116–117) Sitecast concrete two-way flat plate or flat slab (pages 120–123) The absence of lead time for the prefabrication of sitecast concrete allows construction to begin on-site quickly. Sitecast concrete systems without ribs can be formed more quickly than those with more complex profiles.
If you wish to minimize construction time for a building 30 stories or more in height:	Today's tallest buildings are constructed of structural steel or sitecast concrete (systems without ribs), or both in combination. Regional availability of structural materials, availability of skilled trades, construction speed, and costs are all important considerations when choosing one system over another. Steel frame (pages 93, 98–106) Sitecast concrete one-way slab (pages 116–117) Sitecast concrete two-way flat plate or flat slab (pages 120–123)

DESIGN CRITERIA FOR THE SELECTION OF STRUCTURAL SYSTEMS

If you wish to minimize the need for diagonal bracing or shear walls:	Choose a system that is capable of economically forming rigid joints, such as: Steel frame with moment connections (pages 93, 98–106) Single-story rigid steel frame (Page 107) Any sitecast concrete system, particularly those with beams or deepened slabs around the columns (pages 109–125) When depending on a rigid frame for lateral stiffness, column and beam sizes often must be increased in comparison to those of frames stabilized by shear walls or diagonal bracing.
If you wish to minimize the dead load on the building foundation:	Consider lightweight or short-span systems, such as: Any wood system (pages 57–79) Any steel system (pages 93–108)
If you wish to minimize structural distress due to unstable foundation conditions:	Consider lightweight framing systems without rigid joints, such as: Wood light frame (pages 57–65) Lightweight steel framing (pages 93–97) Steel frame, with shear connections (pages 93, 98–106) Precast concrete systems (pages 127–137) Welded steel frames, masonry bearing walls, and sitecast concrete frames are particularly to be avoided.
If you wish to minimize the number of separate trades and contracts required to complete the building:	Consider systems that incorporate many of the functions of a complete wall system in one operation, such as: Masonry construction, including Mill or Ordinary Construction (pages 81–92) Precast concrete loadbearing wall panel systems (pages 130–131)
If you wish to provide concealed spaces within the structure itself for ducts, pipes, wires, and other building mechanical systems:	Consider systems that naturally provide convenient hollow spaces, such as: Wood light frame (pages 57–65) Lightweight steel framing (pages 93–97) Truss and open-web joist systems (pages 64–65, 106) Wood light frame construction and lightweight steel framing are often applied as finish or infill systems in combination with other types of building structures to provide such spaces. For more information on the integration of building services and the structural system, see pages 196–198, 211–214, 261 and 262.

DESIGN CRITERIA: SUMMARY CHART

	WOOD AND MASONRY					STEEL			
	Pages 58–65	Pages 66–73	Pages 74–75	Pages 72–73, 76–79	Pages 81–92	Pages 94–97	Pages 98–106	Page 107	Page 108
GIVE SPECIAL CONSIDERATION TO THE SYSTEMS INDICATED IF YOU WISH TO:	**Wood Light Frame**	**Heavy Timber Construction**	**Cross-Laminated Timber**	**Long-Span Wood Systems**	**Masonry Systems**	**Lightweight Steel Framing**	**Steel Frame**	**Single-Story Rigid Steel Frame**	**Trusses**
Create a building with a highly irregular form:	●				●	●			
Leave the structure exposed while retaining a high fire-resistance rating:		●	●	●	●				
Allow column placements that deviate from a regular grid:							●		
Minimize floor thickness to reduce total building height or to reduce floor spandrel depth on the building facade:			●						
Minimize the area occupied by columns or bearing walls:				●			●	●	●
Allow for changes to the building over time:	●	●				●	●		
Permit construction under adverse weather conditions:	●	●	●	●		●	●	●	●
Minimize site disturbance during construction:		●	●	●			●	●	●
Minimize off-site fabrication time:	●				●	●			
Minimize on-site erection time:		●	●	●			●	●	●
Minimize construction time for a one- or two-story building:	●	●				●	●	●	
Minimize construction time for a 4- to 20-story building:			●				●		
Minimize construction time for a building 30 stories or more in height:							●		
Minimize the need for diagonal bracing or shear walls:							●	●	
Minimize the dead load on the building foundation:	●	●	●			●	●		
Minimize structural distress due to unstable foundation conditions:	●					●	●		
Minimize the number of separate trades and contracts required to complete the building:					●				
Provide concealed spaces within the structure itself for ducts, pipes, wires, and other building mechanical systems:	●					●			

DESIGN CRITERIA: SUMMARY CHART

SITECAST CONCRETE										PRECAST CONCRETE			
Pages 116–117	Pages 116–117	Pages 118–119	Pages 118–119	Pages 120–121	Pages 120–121	Pages 122–123	Pages 122–123	Pages 124–125	Pages 124–125	Pages 134–135	Pages 134–135	Pages 136–137	Pages 136–137
One-Way Solid Slab	**Posttensioned One-Way Solid Slab**	**One-Way Joist**	**Posttensioned One-Way Joist**	**Two-Way Flat Plate**	**Posttensioned Two-Way Flat Plate**	**Two-Way Flat Slab**	**Posttensioned Two-Way Flat Slab**	**Waffle Slab**	**Posttensioned Waffle Slab**	**Solid Slab**	**Hollow-Core Slab**	**Double Tee**	**Single Tee**
●	●			●	●	●	●						
●	●	●	●	●	●	●	●	●	●	●	●	●	●
				●	●	●	●						
	●			●	●	●	●			●	●		
		●	●					●	●			●	●
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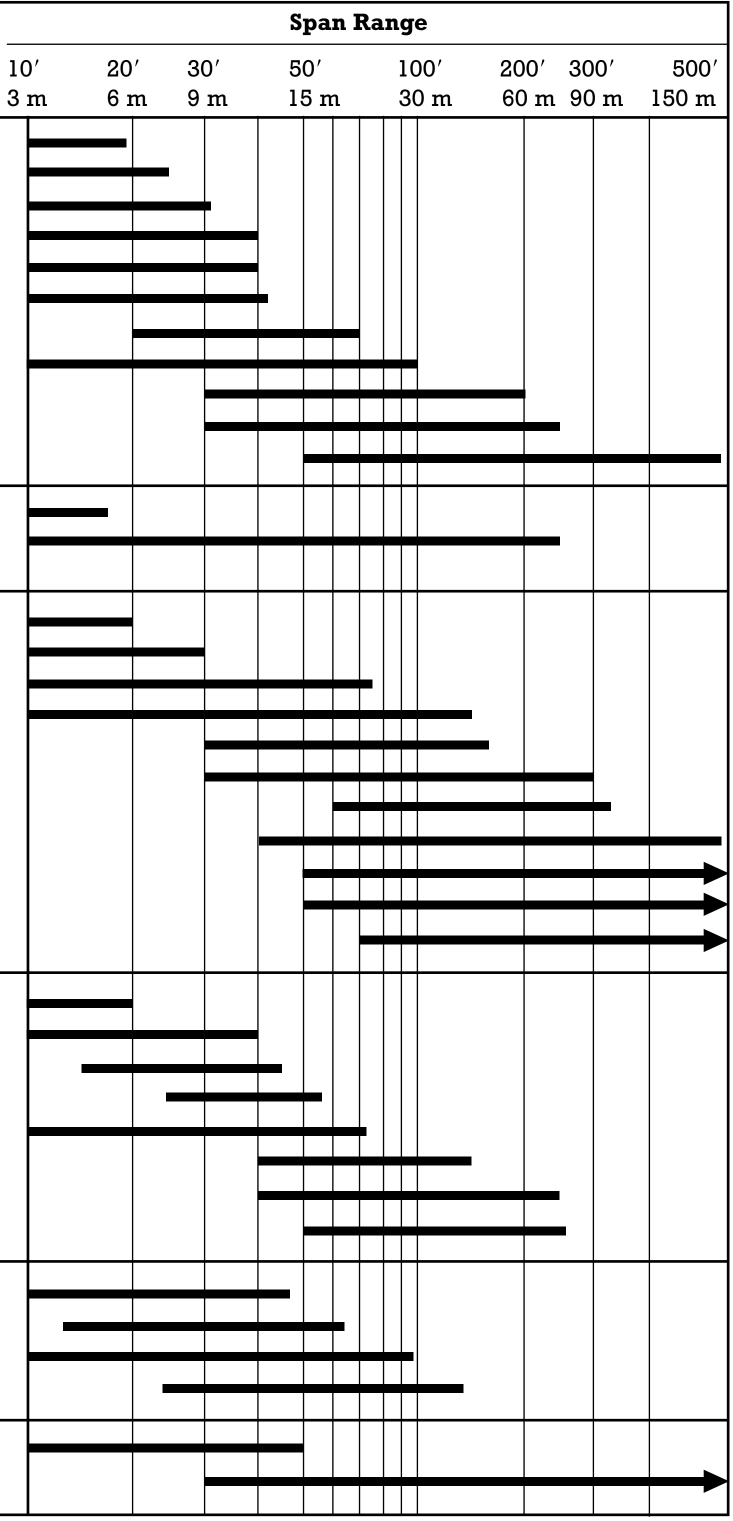
										●	●	●	●
●	●			●	●	●	●			●	●	●	●
●	●			●	●	●	●						
●	●	●	●	●	●	●	●	●	●				
										●	●	●	●

PRACTICAL SPAN RANGES FOR STRUCTURAL SYSTEMS

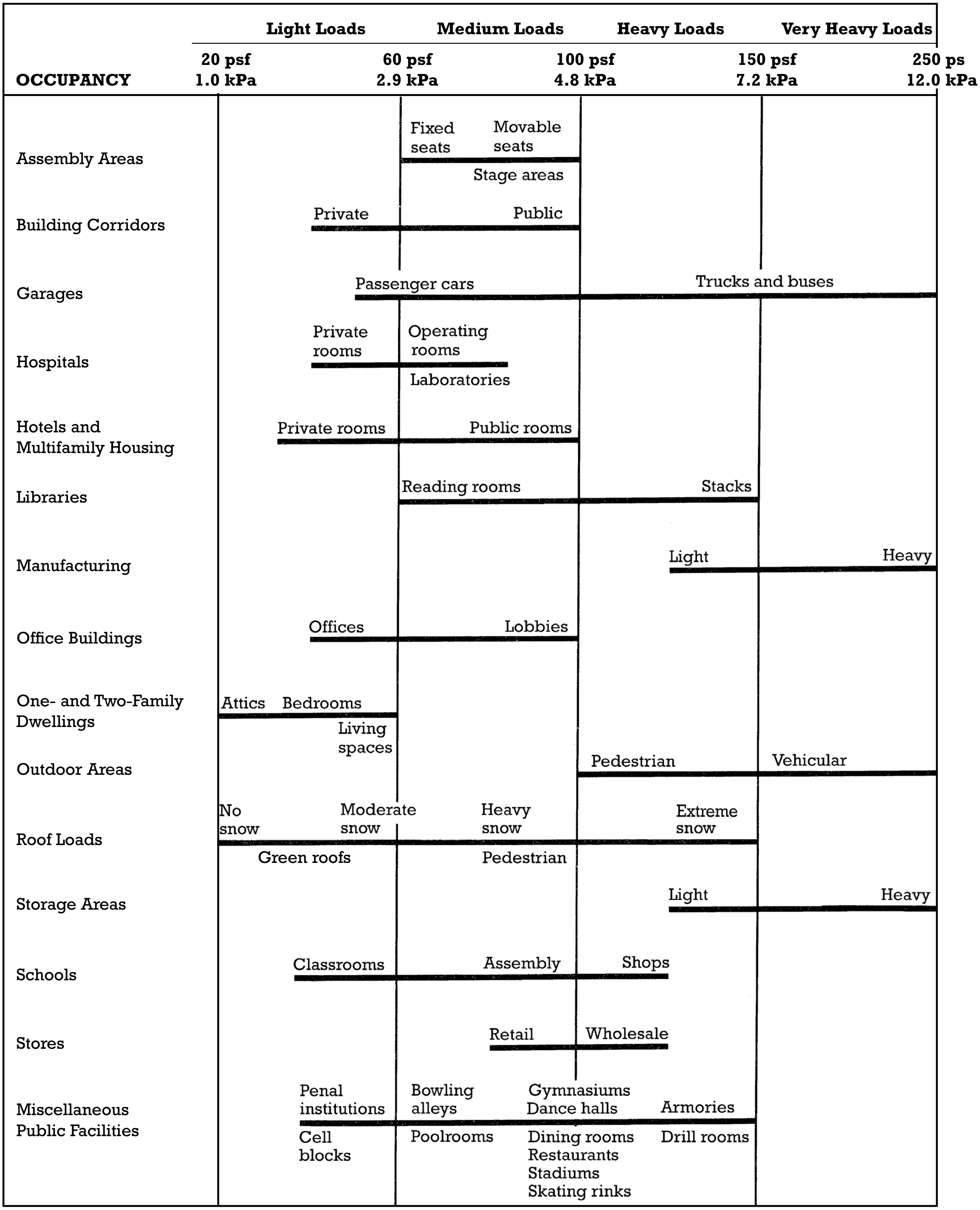
This chart gives common, practical span ranges for various structural systems. Spans beyond the ranges indicated may also be possible in some circumstances. Page references are included where a system indicated is covered in greater detail elsewhere in this book.

STRUCTURAL SYSTEM		Pages
WOOD	Joists	60–61
	Decking	68–69
	Solid Beams	70–71
	Rafter Pairs	62–63
	Cross-Laminated Timbers	74-75
	Light Floor Trusses	64–65
	Light Roof Trusses	64–65
	Engineered Wood Beams	72–73
	Heavy Trusses	76–77
	Glue-Laminated Arches	78–79
	Domes	
BRICK & CONCRETE MASONRY	Lintels	86, 92
	Arches	87
STEEL	Corrugated Decking	102–103
	Lightweight Steel Joists	96–97
	Beams	104–105
	Open-Web Joists	106
	Single-Story Rigid Frames	107
	Heavy Trusses	108
	Arches and Vaults	
	Space Frame	
	Domes	
	Cable-Stayed	
	Suspension	
SITECAST CONCRETE	One-Way Slabs	116–117
	Two-Way Slabs	120–123
	One-Way Joists	118–119
	Waffle Slab	124–125
	Beams	114–115
	Folded Plates and Shells	
	Domes	
	Arches	
PRECAST CONCRETE	Slabs	134–135
	Beams	132–133
	Double Tees	136–137
	Single Tees	136–137
PNEUMATIC	Air-Inflated	
	Air-Supported	



LIVE LOAD RANGES FOR BUILDING OCCUPANCIES

LIVE LOAD RANGES FOR BUILDING OCCUPANCIES



LIVE LOAD RANGES FOR STRUCTURAL SYSTEMS

LIVE LOAD RANGES FOR STRUCTURAL SYSTEMS

STRUCTURAL SYSTEM		Pages	Light Loads	Medium Loads	Heavy Loads	Very Heavy Loads
WOOD	Platform Frame	58–65	━	━		
	Heavy Timber Frame	66–73, 76–79	━	━	━	
	Cross-Laminated Timber	74–75	━	━	━	
MASONRY	Ordinary Construction	81–92	━	━		
	Mill Construction	81–92		━	━	━
STEEL	Lightweight Steel Framing	94–97	━	━		
	Single-Story Rigid Steel Frame	107	━	━	(Roof loads only)	
	Conventional Steel Frame	98–106, 108		━	━	━
SITECAST CONCRETE	One-Way Solid Slab	116–117	━	━	━	
	One-Way Beam and Slab	116–117			━	━
	One-Way Joists	118–119		━	━	━
	Two-Way Flat Plate	120–121	━	━		
	Two-Way Flat Slab	122–123		━	━	━
	Waffle Slab	124–125		━	━	━
	Two-Way Beam and Slab	121–122			━	━
PRECAST CONCRETE	Solid Slab	134–135	━	━	━	
	Hollow-Core Slab	134–135	━	━	━	
	Double Tee	136–137		━	━	━
	Single Tee	136–137		━	━	━

Use the charts on these two pages to identify structural systems suitable for the loads imposed by the activities to take place within the building. Read the chart on the facing page first to determine the live load range associated with the expected building use. Once a load range has been determined, consult the chart on this page to select systems that are recommended within that range. Roof loads are also indicated, to aid in the selection of roof structural systems.

If a building will have multiple uses, read from the chart for the higher load range. Or, if the different uses will be physically separate within the building, the load ranges for each use may be applied to the corresponding areas.

HOW TO USE THE CHART

Use the chart on the facing page to make first-order comparisons of the embodied carbon, global warming impacts of different structural systems. Because providing figures in this simplified format depends on a variety of assumptions and generalizations about the building structure, the information in this chart is most suitable for the earliest stages of building design. As your design progresses, more detailed analyses that can more accurately reflect the specifics of your design and the systems in use should be used.

Wood Products

Wood products are assumed to come from sustainably managed forests. The decrease in global warming potential resulting from biogenic carbon sequestered within the harvested material is accounted for, as is the later increase resulting from carbon emissions that occur at the end of product life when these materials are reused, incinerated, or disposed of in landfill.

Reading Chart Values

Within the range of values provided for each system, read toward the left in the indicated area for structures supporting light loads and toward the right for those supporting heavy loads. (See pages 32–33 for more information about structural systems and load ranges.)

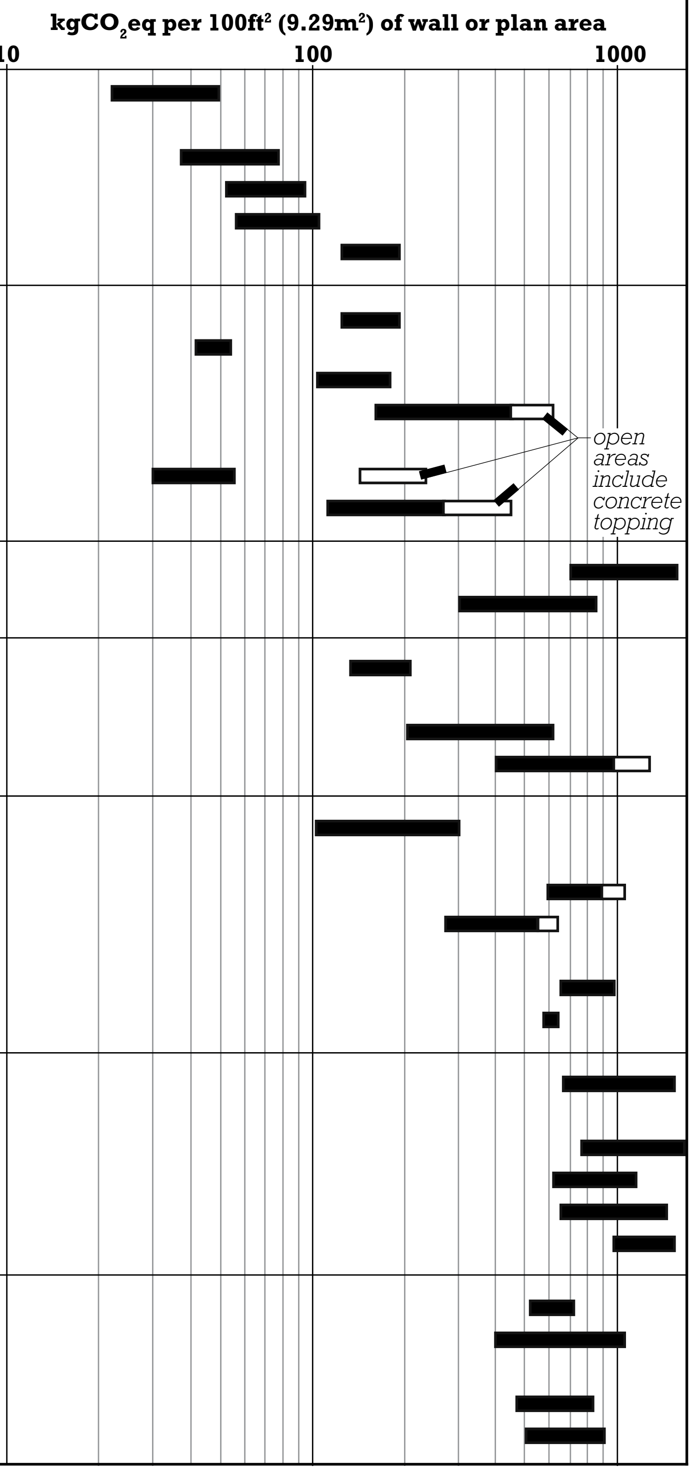
For wall systems, values are for loadbearing walls based on the area of the wall as viewed in elevation (length of wall × height of wall). For floors or roofs, values are for the floor or roof area as viewed in plan. For column and beam systems, values are based on the floor area supported by the system as viewed in plan. For example, a column and beam system consisting of three bays, with each bay measuring 10 feet by 20 feet, would have a total area of 600 square feet (10′ × 20′ × 3 bays = 600 ft^2). For multifloor systems, find the value for one floor and then multiply by the number of floors. Note that the chart scale is logarithmic.

- **Wood light frame walls** include wood stud framing and exterior structural wood panel sheathing on one side of the wall.
- **Wood light frame floors and roofs** include joist or rafter framing and structural wood panel subfloor or roof sheathing.
- **Structural insulated panels** may be used as either wall, floor, or roof components. For walls, read toward the left in the indicated area.
- **Heavy timber post and beam frames** include solid and engineered wood posts, girders, and beams. Residential frames are lightly loaded with relatively short spans. Commercial frames carry heavier loads with longer spans.
- **Cross-laminated timbers** (CLTs) may be used as either wall, floor, or roof components. For walls, read toward the far left in the indicated area. For CLT floors with concrete topping, read in the open area indicated.
- **Heavy timber floor and roof decking** includes solid and glue-laminated wood. For floor decking with concrete topping, read in the open areas indicated.
- **Masonry walls** include masonry units, mortar, grout, and reinforcing.
- **Lightweight steel walls** include light-gauge metal framing and exterior gypsum sheathing on one side of the wall.
- **Lightweight steel floors and roofs** include light-gauge metal framing with either structural wood panel sheathing or steel decking as indicated. For metal decking with concrete topping, read in the open area indicated.
- **Structural steel columns and girders** include wide-flange columns and the girders that span the columns.
- **Structural steel floors and roofs** include wide-flange steel or open-web steel floor framing and metal decking. For floor decking with concrete topping, read in the open areas indicated.
- **Single-story rigid steel frame** includes the steel rigid frame, purlins, and metal decking on one side of the framing. To calculate the global warming potential of a complete building frame, find the values for each wall area and roof area, and then add these values together.
- **Sitecast and precast concrete columns and beams** include reinforced columns and beams (if any) spanning between the columns.
- **Sitecast and precast concrete walls** include concrete and reinforcing. For integrated concrete formwork (ICF), the permanent forming material is also included.
- **Sitecast and precast concrete slabs** include slab systems spanning columns and/or beams.

GLOBAL WARMING IMPACT OF STRUCTURAL SYSTEMS

Use this chart to compare the relative global warming potentials of different structural systems. Values are cradle-to-grave life cycle, based on United States commercial construction averages, over a 60-year building life, and expressed as equivalent kilograms of carbon dioxide per 100 square feet (9.29 m^2) of wall, floor, or roof area.

STRUCTURAL SYSTEM		Pages
WOOD LIGHT FRAME	Walls	58–59
	Floors & Roofs:	
	Solid Wood Joists & Rafters	60–63
	I-Joists	60–63
	Light Trusses	64–65
	Structural Insulated Panels	
HEAVY TIMBER & MASS TIMBER	Post & Beam Frames:	
	Residential	64–71
	Commercial	64–73
	Cross-Laminated Timbers	74–75
	Floor & Roof Decking:	
	Solid Wood	68–69
	Glue-Laminated	68–69
MASONRY	Brick Masonry Walls	84–85
	Concrete Masonry Walls	90–91
LIGHT-WEIGHT STEEL	Walls	94–95
	Floors & Roofs:	
	With Wood Panel Sheathing	96–97
	With Metal Decking	96–97
STRUCTURAL STEEL	Columns & Girders	98–99, 104–105
	Floors & Roofs:	
	WF Beams	104–105
	OWSJ	106
	SS Rigid Steel Frame:	
	Wall Area	107
	Roof Area	107
SITECAST CONCRETE	Columns & Beams	110–111, 114–115
	Walls:	
	Cast-In-Place	112–113
	Tilt-Up	
	ICF	
	Floors & Roofs	114–125
PRECAST CONCRETE	Column & Beams	128–129, 132–133
	Walls	130–131
	Slabs:	
	Solid & Hollow Core	134–135
	Double Tee	136–137



SOME TYPICAL CHOICES OF STRUCTURAL SYSTEMS FOR DIFFERENT BUILDING TYPES

Use the chart on these two facing pages to identify common structural systems used for various building types.

	WOOD AND MASONRY					STEEL				
	Pages 58–65	Pages 66–73	Pages 74–75	Pages 72–73, 76–79	Pages 81–92	Pages 94–97	Pages 98–105	Page 106	Page 107	Page 108
BUILDING TYPE	**Wood Light Frame**	**Heavy Timber Construction**	**Cross-Laminated Timber**	**Long-Span Wood Systems**	**Masonry Systems**	**Lightweight Steel Framing**	**Steel Frame**	**Open-Web Joists**	**Single-Story Rigid Steel Frame**	**Trusses**
Arenas							●	●		●
Concert halls							●			●
Hospitals, laboratories					●	●	●	●		●
Industrial & warehouse buildings		●	●	●	●		●	●	●	●
Institutional buildings, small to medium size	●		●		●	●	●	●		
Institutional buildings, large							●	●		●
Office buildings, small to medium size	●	●	●		●	●	●	●		
Parking garages							●			
Places of worship	●	●	●	●	●	●	●	●	●	
Residential buildings, one- and two-family	●	●			●	●				
Residential buildings, small to medium-size multifamily	●		●		●	●				
Residential buildings, large multifamily			●		●					
Schools		●	●		●		●	●		
Shopping malls					●		●	●		
Tall buildings			●				●	●		
Theaters				●	●		●	●	●	

SOME TYPICAL CHOICES OF STRUCTURAL SYSTEMS FOR DIFFERENT BUILDING TYPES

SITECAST CONCRETE						PRECAST CONCRETE		
Pages 114–115	Pages 116–117	Pages 118–119	Pages 120–121	Pages 122–123	Pages 124–125	Pages 132–133	Pages 134–135	Pages 136–137
Beams & Girders	One-Way Solid Slab	One-Way Joist	Two-Way Flat Plate	Two-Way Flat Slab	Waffle Slab	Beams & Girders	Solid & Hollow-Core Slab	Single & Double Tee
●	●					●	●	
●	●			●	●			
●	●			●		●	●	
●	●			●	●	●	●	●
●	●		●	●		●	●	
●	●	●	●	●		●	●	
●	●		●	●		●	●	
●	●	●		●		●	●	●
●	●	●		●		●	●	
			●	●		●	●	
●	●	●		●		●	●	
●			●	●	●	●	●	
●			●	●		●	●	
●	●	●	●	●		●	●	

2 CONFIGURING THE STRUCTURAL SYSTEM

This section will aid you in making a preliminary layout of the structural system of your building.

LATERAL STABILITY AND STRUCTURAL SYSTEMS

STABILIZING ELEMENTS

All buildings must be designed to resist the lateral forces of wind and earthquakes. Three basic structural configurations may be used, either singly or in combination: the shear wall, the braced frame, and the rigid frame. The choice of the system and the location of its elements will have an important influence on the form of the building and the arrangement of its interior spaces.

Shear Walls

Shear walls are stiff walls engineered to resist the effects of lateral forces. Although most often constructed of reinforced concrete, they can be made of almost any structural material and range in size from small sections of panel-sheathed wood stud walls in residential buildings to massive steel-and-concrete assemblies in the tallest buildings. In comparison to the other systems described on this page, shear walls are especially stiff, making them a good choice wherever a relatively compact arrangement of stabilizing elements is needed. Shear walls must be mostly solid, with only limited openings. To minimize interference with floor plan arrangements, they are frequently incorporated into building cores, stair towers, or other internal vertical structures. Shear walls can also be part of the exterior wall, although in this location they limit access to daylight and exterior views.

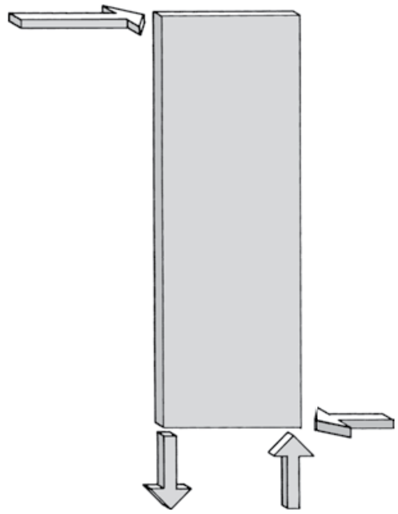
Braced Frames

Braced frames are composed of open triangulated frameworks, most often constructed of steel or wood. In terms of strength per weight, they are the most efficient lateral force-stabilizing system. Like shear walls, braced frames are often incorporated into the building core or other internal vertical structures. They can also be part of the exterior wall, where they may become a significant aesthetic element in the building's design.

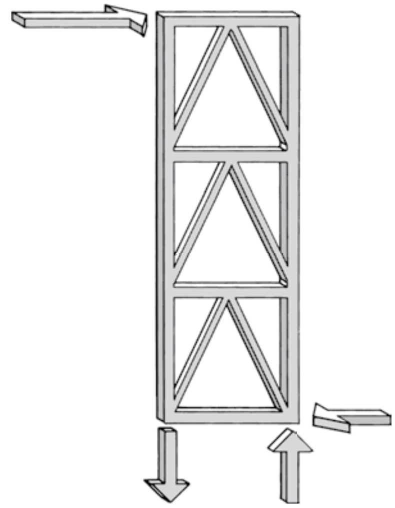
When either shear walls or braced frames are used to provide lateral stability, the building frame itself does not need to provide its own lateral force resistance. This allows column-to-beam connections to be of a type that are relatively easy and inexpensive to construct, called shear connections.

Rigid Frames

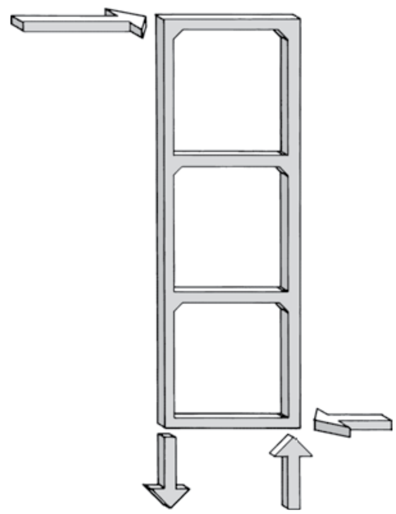
Rigid frames (also called *moment-resisting frames*) depend on stiffer and more difficult to construct column-to-beam connections, called moment connections. The use of moment connections results in greater resistance to lateral forces within the building frame itself. These connections are most easily constructed in steel or sitecast concrete. Or, with greater difficulty, they may be constructed in precast concrete. The absence of solid walls or added diagonal bracing makes this lateral force-resisting system attractive where the least interference in plan configuration or elevation is desired. However, rigid frames, on their own, tend to be a less structurally efficient lateral force-resisting system. They are most readily employed in low or broad structures requiring relatively modest lateral force resistance. In taller buildings, rigid, or sometimes semi-rigid, connections are more often used in combination with either shear walls or braced frames. In addition, the rigid frame introduces additional stresses into the building frame. This frequently results in columns and beams that are heavier or a closer column spacing than would otherwise be required.



SHEAR WALL



BRACED FRAME

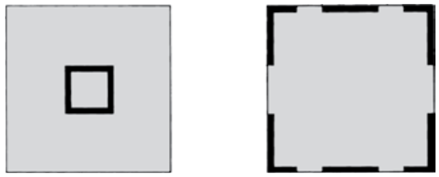


RIGID FRAME

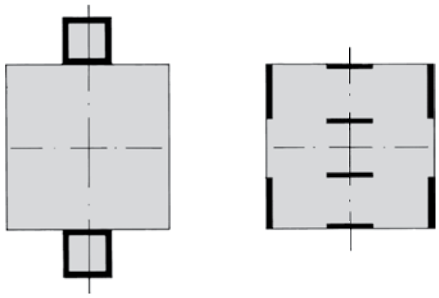
CONFIGURING STABILIZING ELEMENTS

The arrangement of shear walls, braced frames, and rigid frames in a structure is important to their effectiveness in resisting lateral forces acting on the building. As illustrated in the adjacent schematic floor plans, these elements may be placed within the interior of the building or at the perimeter, and they may be combined in a variety of ways. However, they must be arranged so as to resist lateral forces acting from all directions. This is usually accomplished by aligning one set of stabilizing elements along each of the two major plan axes of the building. Stabilizing elements must also be arranged in a balanced fashion in relation to the mass of the building. Arrangements that displace the center of resistance far away from the building's center of mass may lead to difficult-to-control movements or excessive stresses under lateral load conditions.

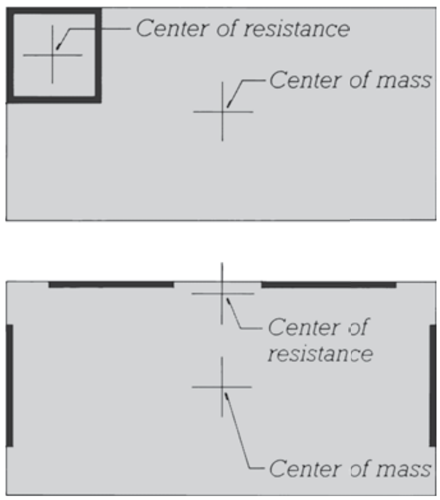
In general, lateral force-resisting elements are heaviest and most extensive at the base of a building, and diminish in size and extent toward the top of the building. In addition, considerations of lateral stability become increasingly important as the height and slenderness of the building increase. The configuration of stabilizing elements is discussed further on the following pages.



Stabilizing elements may be placed within the interior or at the perimeter of a building.



Stabilizing elements should be arranged in a balanced fashion and to resist lateral forces from any direction.



Avoid unbalanced arrangements of stabilizing elements that result in the displacement of the center of lateral force resistance away from the building's center of mass.

SELECTING STABILIZING ELEMENTS

This chart indicates the methods of resisting lateral forces most common for each structural system. More detailed information on the structural systems can be found on the pages noted in the chart.

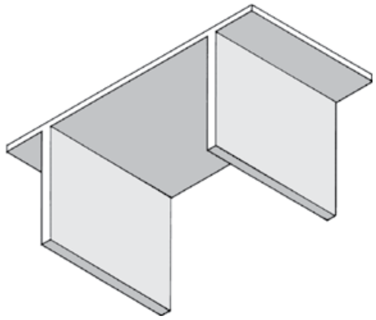
STRUCTURAL SYSTEM		Pages	Rigid Frame	Semi-Rigid Joints w/Supplemental Braced Frame or Shear Wall	Braced Frame	Shear Wall
WOOD	Wood Light Frame	58–65			● Let-in bracing	● Panel sheathing
	Cross-Laminated Timber	74–75				● CLT panels (low-rise), site-cast concrete (high-rise)
	Heavy Timber Frame	66–72	● Glue-laminated		● Timber bracing	● Diagonal or panel sheathing
MASONRY	Ordinary Construction	81–92				● Masonry walls
	Mill Construction	81–92				● Masonry walls
STEEL	Light-Gauge Steel Framing	94–97			● Strap bracing	● Panel sheathing
	Single-Story Rigid Frame	107	● Parallel to frames only		● Perpendicular to frames	
	Conventional Steel Frame	98–106	● Requires welded connections	●	●	● Sitecast concrete
SITECAST CONCRETE	One-Way Solid Slab	116–117	O May require added structure	●		
	One-Way Beam and Slab	116–117	●	●		
	One-Way Joist	118–119	●	●		
	Two-Way Flat Plate	120–121	O May require added structure	●		
	Two-Way Flat Slab	122–123	O May require added structure	●		
	Waffle Slab	124–125	●	●		
	Two-Way Beam and Slab	120–121	●	●		
PRECAST CONCRETE	Solid Slab	133–135	O With special connection design		O Uncommon	●
	Hollow Core Slab	134–135	O With special connection design		O Uncommon	●
	Double Tee	136–137	O With special connection design		O Uncommon	●
	Single Tee	136–137	O With special connection design		O Uncommon	●

● Recommended

O Feasible in some circumstances, but less common

VERTICAL LOAD-RESISTING ELEMENTS

All structural systems consist of some combination of vertical and horizontal elements to enclose a building. Wall and slab systems are composed of loadbearing walls spanned by horizontal slabs. The placement of walls is restricted, as they must be located to support the loads from slabs and walls above. Due to the significant presence of the walls in the plan of the building, the use of a wall and slab system generally implies a close correspondence between the structural module and the organization of building functions. In addition, economic considerations usually dictate that the arrangement of walls be as uniform as possible, making this system particularly attractive for building types that require regular arrangements of uniformly sized spaces, such as apartments, schools, and hotels.

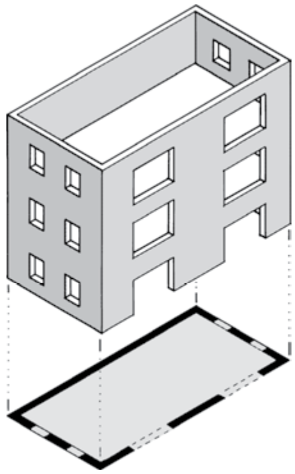


WALL AND SLAB SYSTEMS ***(shown from below)***

LATERAL LOAD-RESISTING ELEMENTS

The regularly placed loadbearing walls used in this system are generally well suited to acting as shear walls for lateral stability. They may be used alone, or they may be combined with rigid frames or braced frames where structural walls run in only one direction in a building.

When used alone, shear walls must be arranged to resist lateral forces in all directions, such as in some variation of a complete or partial box form. Shear walls should always be placed as symmetrically as possible in the building plan, particularly in taller buildings. The sizes and spacing of openings through shear walls should be limited in size and quantity.

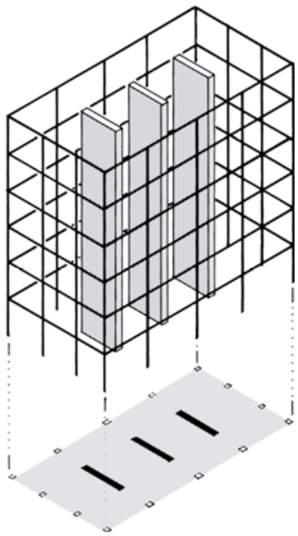


Shear walls may be arranged in a box form to resist lateral forces from all directions.

SYSTEMS WELL SUITED TO WALL AND SLAB FRAMING

Bearing walls of any type may be used to create wall and slab structural systems. See the following sections for more information:

Systems	**Pages**
Wood Stud Walls	58–59
Cross-Laminated Timber	74–75
Brick Masonry Walls	84–85
Concrete Masonry Walls	90–91
Lightweight Steel Stud Walls	94–95
Sitecast Concrete Walls	112–113
Precast Concrete Wall Panels	130–131

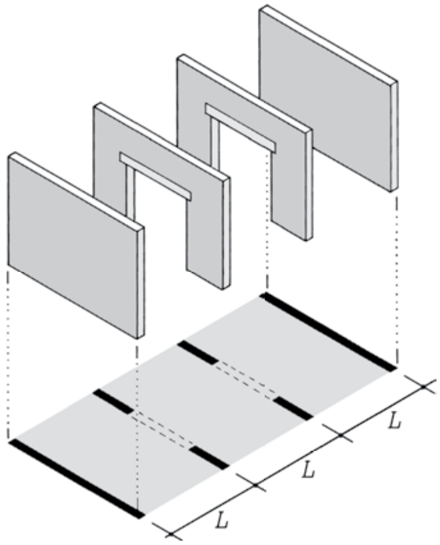


When combined with other stabilizing mechanisms, shear walls may be arranged so as to resist forces in only one direction.

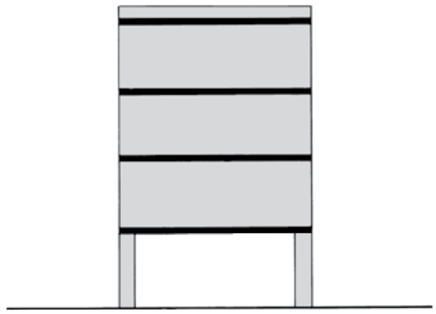
WALL AND SLAB SYSTEM LAYOUTS

The distance between walls is equal to the span of the slab or floor system supported by the walls. Walls can be any length but are required wherever slabs are supported. Where necessary, openings in walls can be made by including beams over such openings to carry loads from above. In multistory buildings, the locations of bearing walls should coincide from floor to floor. However, where it is desirable to omit bearing walls from a lower floor, it may be possible to design the wall above as a deep beam supported at its ends only.

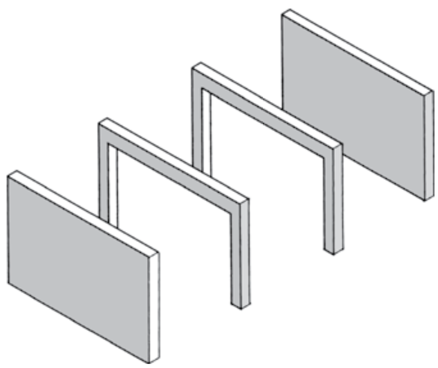
Wall and slab systems can be combined with column systems to permit greater open areas in a plan. Wherever possible, keep walls in locations that are most desirable for lateral load resistance.



In wall and slab systems, the distance between walls is equal to the span of the slab above. Openings in walls may be made when beams are added to carry loads from above.



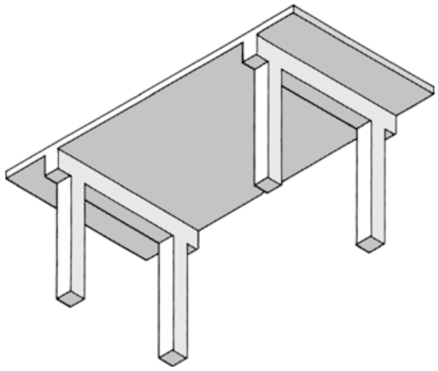
Bearing walls may act as deep beams to span openings below, as shown in this schematic cross section.



Bearing wall and column systems may be combined for more flexibility in plan layouts.

VERTICAL LOAD-RESISTING ELEMENTS

Column and beam systems are composed of vertical columns, horizontally spanning girders and beams, and slabs spanning the area between the beams. Compared to wall and slab systems, column and beam systems place fewer constraints on the organization of space within a building. Where the size or arrangement of interior space does not correspond with the structural module, where maximum open space is desired, or where a high degree of flexibility in the use of space over time is desired, column and beam systems are a good choice. Compared to column and slab systems, column and beam systems are also practical over a greater range of spans and bay proportions.

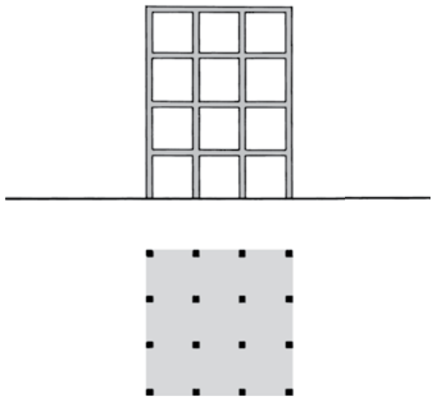


COLUMN AND BEAM SYSTEMS ***(shown from below)***

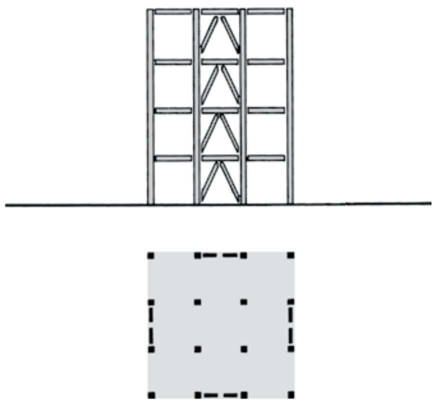
LATERAL LOAD-RESISTING ELEMENTS

Column and beam systems of steel frame or sitecast concrete construction are well suited to act as rigid frames for some or all of the structure's lateral force resistance. In sitecast concrete, beam-to-column moment connections are usually easily produced as a normal feature of the system. In steel, moment connections are readily constructed, although at added cost. Moment connections are most difficult to construct and less frequently used in precast concrete structures. Rigid frame structures minimize or eliminate the need for diagonal bracing or shear walls, making them a good choice where the least obstruction in plan is desired. However, rigid frames also depend on regular, orthogonal column placements, and often require deeper beams and columns that are more closely spaced, larger in dimension, or more heavily reinforced than would otherwise be required. Rigid frames are normally not well suited for structures with unusually long spans or tall, slender columns.

When braced frames or shear walls are used for lateral stability, columns and beams may be joined with simple shear connections, such as the bolted connections normally used in steel and timber structures or the flexible welded connections used in precast concrete. The stabilizing braces or walls may be located within the interior of the building or at the perimeter, but they must be placed so as to resist lateral forces in all directions. Building cores or stair towers housing vertical circulation or other systems are frequently designed to incorporate such elements, leaving the remainder of the floor plan free of obstruction. When located at the perimeter of the structure, these elements will, to varying degrees, influence the appearance and limit the openness of the building façade.



Rigid frame structures require no additional bracing or shear walls, as shown in this elevation and plan.



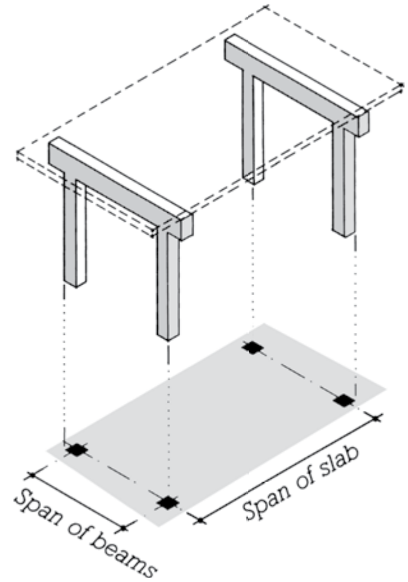
The locations of braced frames or shear walls must be considered in relation to the elevation and plan of a building.

COLUMN AND BEAM SYSTEMS

SYSTEMS WELL SUITED TO COLUMN AND BEAM FRAMING

Information on column and beam systems can be found in the following sections:

Systems	**Pages**
Wood Beams	70–73
Steel Beams and Girders	104–105
Sitecast Concrete Beams and Girders	114–115
Precast Concrete Beams and Girders	132–133



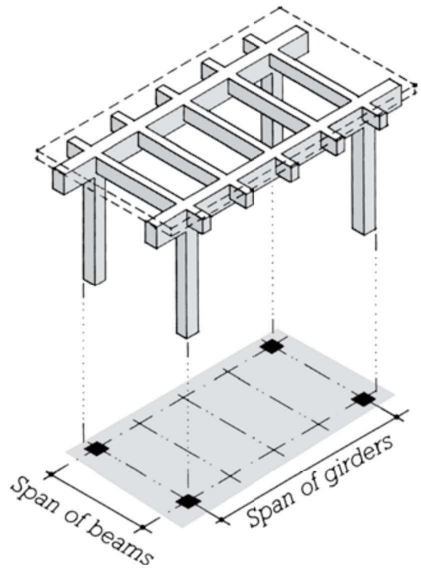
In column and beam systems, columns are located on beam lines.

COLUMN AND BEAM SYSTEM LAYOUTS

Columns are located on the lines of the beams above. Although column spacings may vary within the limits of the spanning capacity of the beams, for reasons of economy, regular gridded arrangements are preferred wherever practical.

Various combinations of beams and slabs are possible. Beams can span in one direction only, with slabs spanning perpendicular to them. With this arrangement, column spacing in one direction is equal to the span of the beams; in the other direction, it is equal to the span of the slabs.

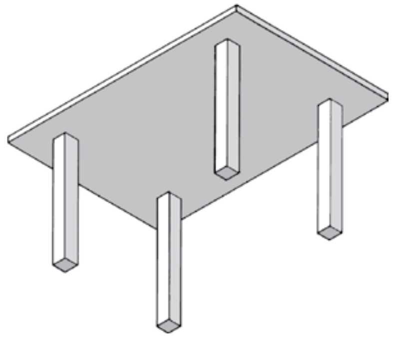
More flexibility in the location of columns can be achieved with beams spanning in both directions. Deeper beams, termed *girders*, span the columns. The girders, in turn, support shallower secondary beams, spanning perpendicular to them. Finally, the distance between the secondary beams is spanned by the slab. Column spacings with such beam and girder arrangements are limited only by the spanning capacity of the beams in either direction. The choice of the direction of the span of the girders and beams in such a structure can be influenced by a variety of factors, including the relative structural efficiency of either arrangement, the lateral stability requirements for the overall structure, and the integration of the floor structure with other building systems such as electrical wiring in the slab or ducts and piping running beneath the floor framing. These considerations are covered in more detail in the sections of this book that discuss specific structural and mechanical systems.



Beams span both directions in beam and girder systems.

VERTICAL LOAD-RESISTING ELEMENTS

Column and slab systems are composed of vertical columns directly supporting horizontally spanning slabs without intermediary beams. As with column and beam systems, the reliance on columns for vertical load support permits greater independence between the building plan and the structural system. The absence of beams in column and slab systems may permit even greater flexibility in column placements than with column and beam systems, because columns are not restricted to beam lines. Column and slab systems may also be attractive economically due to the simplification of construction techniques and the reduction in total floor depths that they make possible. Most column and slab systems are constructed of sitecast concrete.

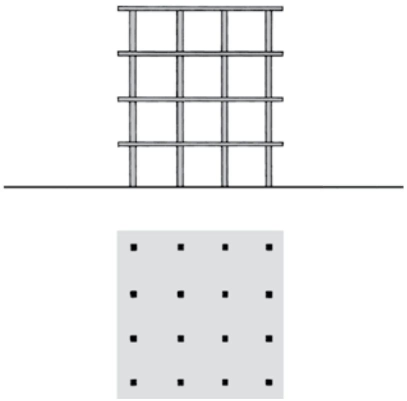


COLUMN AND SLAB SYSTEMS (*shown from below*)

LATERAL LOAD-RESISTING ELEMENTS

Rigid frame action is sometimes possible in column and slab systems, although its effectiveness depends on the depth of the slab, particularly in the areas close to the columns. Where large lateral forces are expected in systems with shallow slabs, a deepening of the slab or the addition of structural beams between columns may be required to achieve the needed lateral force resistance.

Shear walls or braced frames may also be used to develop lateral resistance in column and slab systems. These elements may be used either as the sole means of lateral bracing or as enhancements to the rigid frame action of the system. They may be located within the interior of the building or at the perimeter, but they must be placed so as to resist lateral forces in all directions. The locations of interior elements must be coordinated with the building plan. Building cores or stair towers housing vertical circulation or other systems are frequently designed to incorporate such elements, leaving the remainder of the floor plan free of obstruction. When located at the perimeter of the structure, these elements will, to varying degrees, influence the appearance and limit the openness of the building façade.

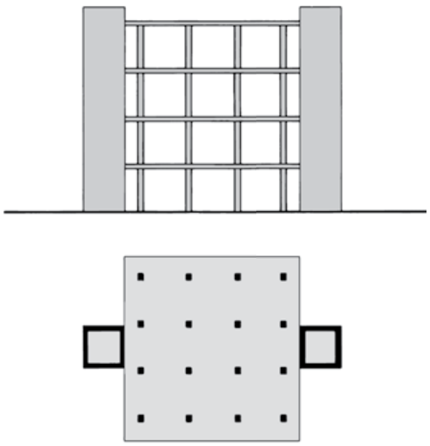


As shown in this elevation and plan, rigid frame action is possible with column and slab systems, although its effectiveness is limited.

SYSTEMS WELL SUITED TO COLUMN AND SLAB FRAMING

Conventional structural systems that are configured as column and slab systems are metal space frame, and a number of sitecast concrete systems, including two-way flat plate, two-way flat slab, and either one-way joist or waffle slab construction. For further information, see the following sections:

Systems	Pages
Sitecast Concrete Two-Way Flat Plate	120–121
Sitecast Concrete Two-Way Flat Slab	122–123
Sitecast Concrete One-Way Joists	118–119
Sitecast Concrete Waffle Slab	124–125



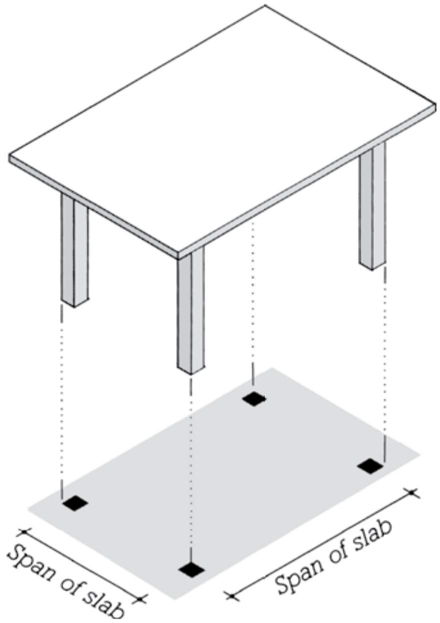
Shear walls are frequently used with column and slab systems to provide greater resistance to lateral forces. In this elevation and plan, the shear walls are shown incorporated into a pair of vertical cores.

COLUMN AND SLAB SYSTEM LAYOUTS

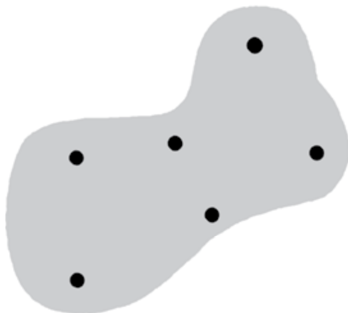
Column spacing in either direction is equal to the span of the slab. For maximum economy and structural efficiency, column bays should be roughly square in proportion and columns should be arranged along regularly spaced bearing lines. However, where driven by design considerations, column and slab systems can tolerate deviations in standard column placements, variations in bay sizes, and irregular plans shapes.

STRUCTURAL LIMITATIONS OF COLUMN AND SLAB SYSTEMS

The absence of beams in sitecast concrete flat plate and flat slab construction imposes some structural limits on these systems. The relatively shallow depth of the joint between the columns and slabs can restrict their vertical load-carrying capacity and limit their resistance to lateral forces. Although the addition of beams to these systems adds substantially to construction costs, it may be a practical alternative where longer spans are required, very heavy loads must be carried, or additional lateral resistance is needed and the use of shear walls or braced frames is undesirable. Such configurations are covered in more detail in the sections describing these structural systems.



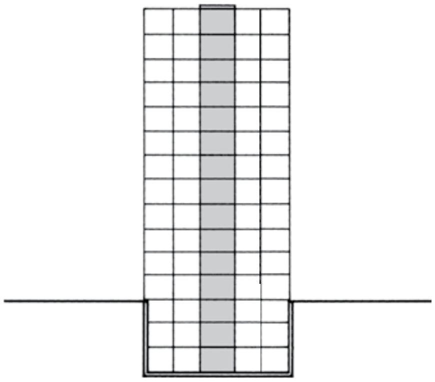
In column and slab systems, the span of the slab is equal to the column spacing in either direction.



The absence of beams in column and slab systems facilitates irregular column layouts or plan shapes.

THE DESIGN OF TALL BUILDING STRUCTURES

As a building's height increases, the design of its structural system becomes increasingly specialized. The large cumulative effect of vertical loads, site-specific conditions related to wind, earthquakes, and soils, the regional availability and costs of various construction systems, and spatial requirements of the building program will all influence the selection, form, and configuration of the building structure. The information on the following pages describes structural options available for tall building design in relation to some of these considerations. Given the unique demands on tall building structures, a structural designer should participate in even the earliest phases of tall building design.



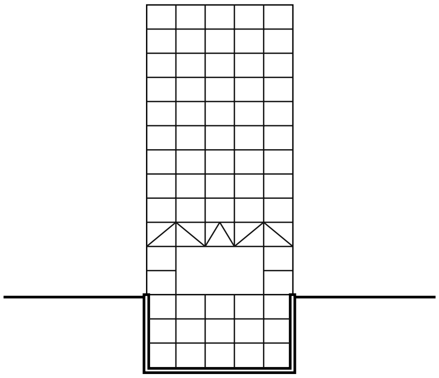
Major loadbearing elements should be continuous vertically to the foundations of the building.

VERTICAL LOAD–RESISTING SYSTEMS

The vertical load–resisting systems for mid- and high-rise buildings are essentially variations on those for low-rise structures described in the previous pages. In the tallest buildings, column and beam or column and slab systems are most common due to their efficient use of space, structural versatility, and ease of construction.

Because of the large gravity loads associated with taller structures, special care should be taken that major structural elements are not interrupted vertically. To the greatest extent possible, building core structures, columns, and other loadbearing elements should extend continuously to the foundation, and should avoid offsets from floor to floor or other discontinuities.

Nevertheless, conditions may arise in which not all loadbearing elements can have direct and continuous paths to the building's foundation: In tall buildings, it is often structurally advantageous to redistribute vertical loads outward toward the building corners to increase resistance to overturning; larger open spaces in lower floors, such as commercial areas, public auditoriums, lobbies, or atria, may require column-free configurations that interrupt the paths of structural elements from above; column locations in parking levels may not align with those on floors above; or other variations in program requirements or building massing may necessitate offsets in the arrangement of structural elements. In such cases, where only minor changes in load paths are required, columns may be subtly angled or shifted between floors. Where more significant redistributions of load are required, transfer beams or heavy, long-span truss structures may be used. In other cases, changes in the selection of structural system or its basic configuration and design may be appropriate.



Transfer beams or trusses may be used to interrupt vertical loadbearing elements where necessary.

LATERAL LOAD–RESISTING SYSTEMS

Increasing the height of a building increases its sensitivity to lateral forces. The taller the building, the more these forces will dictate the design of the structure, and the more they will influence building form. In the world's tallest buildings, structural design is driven foremost by resistance to wind loads, more so than either gravity loads or lateral earthquake forces. The following guidelines are particularly important in the design of very tall buildings.

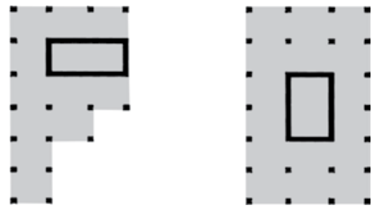
As building height increases, expect the lateral support system to increase in prominence within the design. Lateral force–resisting elements may become heavier, may be more closely spaced, or may increase in horizontal extent, and the choice of suitable systems and their configuration may become more limited.

Designs that are asymmetric in plan, that are unbalanced in their massing, or that have irregular arrangements of stabilizing elements become increasingly problematic in taller buildings. Under the influence of lateral loads, these conditions can lead to difficult-to-control building motions or excessive stresses in structural elements. These conditions should be avoided.

Where large buildings are composed of discrete masses, each part can be expected to move differently under the conditions associated with lateral loads. The leg of an L-shaped building, the stem of a T-shaped building, a tower offset to one corner of a wider base, or other such unsymmetrical arrangements are prone to adverse interactions under dynamic conditions. Where these occur, each mass may be designed as an independent structure, with substantial joints between the abutting masses that can safely absorb differential movements between them.

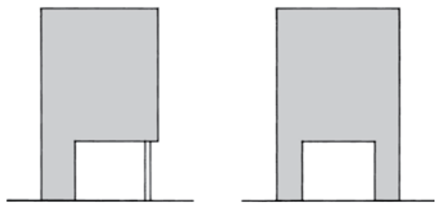
Buildings of inherently unstable massing or form should be avoided. Large or irregular openings in floor plates are detrimental, especially those constituting 50% or more of the overall floor area. Discontinuities in the stiffness of a structure at different levels should be avoided. For example, an open space with long horizontal spans at the base of a tall building can produce excessive flexibility or weakness at that level. If such a "soft story" cannot be avoided, extra effort to provide adequate lateral support at that level may be required.

Tall buildings may interact with the wind in a variety of ways that do not lend themselves to simple generalizations. Wind forces can cause oscillation or twisting of the building structure, lateral accelerations that are uncomfortable for occupants, or localized areas of excessively high pressure acting on the building façade. As the wind moves over and around the building, it can cause uncomfortably high air speeds at the base of the building or nearby, or have adverse impacts on structures downwind. Many of the world's tallest buildings rely on subtle manipulations of the building skin and profile to mediate such effects. Because of the complexity of these interactions, designs for very tall buildings are typically subject to mathematical modeling and physical wind tunnel testing from the earliest phases of design. The results of these investigations are used to minimize adverse effects through adjustments in building massing, structural response, façade orientation, and surface articulation.



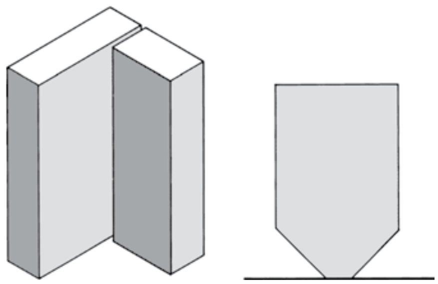
UNBALANCED PLAN

BALANCED PLAN

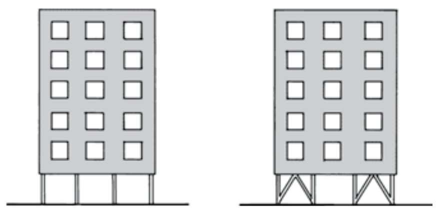


UNBALANCED SECTION

BALANCED SECTION



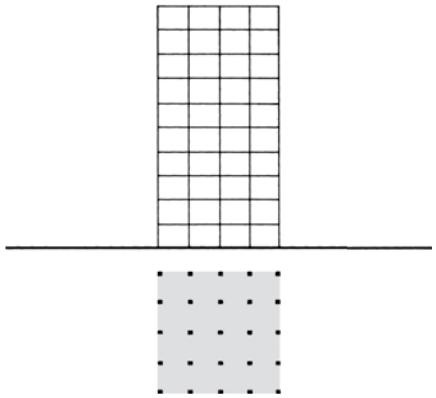
Discrete building masses should be structurally independent. Inherently unstable building masses should be avoided.



Discontinuities in the stiffness of structures at different levels should be avoided, or additional stabilizing elements may be required.

TALL BUILDING STRUCTURES

As building height increases, design for lateral force-resistance becomes increasingly specialized. The following configurations of lateral force–resisting systems are presented in order of applicability to structures of increasing height. The adjacent diagrams illustrate diagrammatically in both plan and section the configurations described.

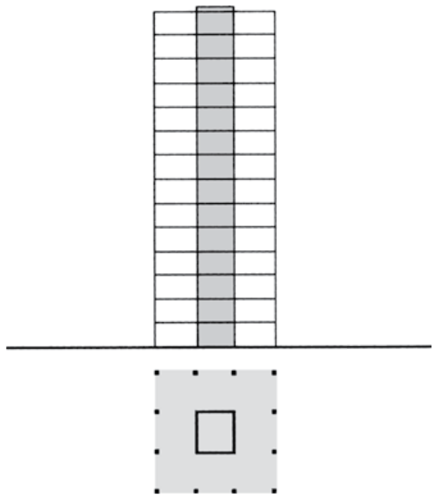


RIGID FRAME

CONVENTIONAL STRUCTURAL CONFIGURATIONS

For buildings up to approximately 20 to 25 stories in height, the conventional arrangements of shear walls, braced frames, and rigid frames, as previously discussed in this chapter, may be used. The same considerations that apply to low-rise buildings apply to these taller buildings as well: Stabilizing elements should be arranged to resist lateral forces along all major axes of the building, these elements should be arranged in a balanced manner, and they may need to be integrated with the building plan or elevation.

Shear walls and braced frames are the stabilizing elements most used in buildings in this height range due to their structural efficiency and ease of construction. They may be used either separately or in combination. The use of rigid frame systems as the sole means of achieving lateral stability in buildings of this height is also possible, although they are more frequently used in combination with either shear walls or braced frames, thereby achieving greater efficiency at lower cost.



SHEAR WALL CORE

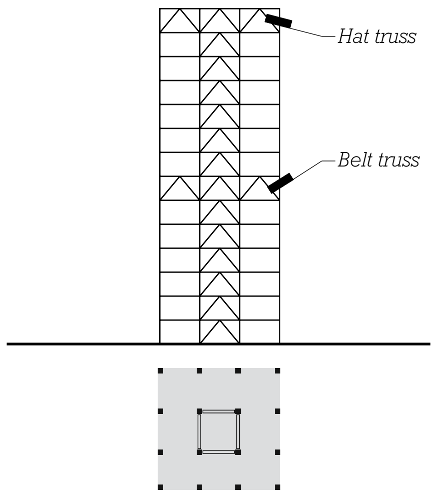
CORE STRUCTURES

Core structures are among the most common of stabilizing configurations for tall buildings. Enclosed vertical structures, used to house vertical circulation and other building services, are structured to also provide lateral stability. One of the principal advantages of core structures is that with the placement of the lateral force–resisting elements in one or more central building cores, interference with the building plan and elevation are minimized. In concrete construction, the walls that enclose stairways, elevators, and such can be designed to also act as shear walls. In steel construction, core structures are designed as braced frames.

To ensure balanced resistance to lateral loads from any direction, a single core servicing an entire building should be located in plan close to the center of the building. Or where there is more than one core, the cores should be placed in a roughly balanced arrangement around the center. Such cores typically comprise approximately 20% to 25% of the total floor area of a mid- to high-rise building. Where the core walls are constructed as shear walls, openings through the walls should be kept to the minimum necessary for access to the stairs, elevators, and other service spaces within the core. Buildings stabilized by simple core structures can reach heights of 35 to 40 stories.

Core structures can be used to stabilize buildings taller than 40 stories by linking the core (or cores) with columns at the perimeter of the building. By allowing the core and these perimeter elements to work in tandem, greater lateral force resistance is achieved. These links, or *outriggers*, may consist of steel trusses a full story or more in height, or of concrete shear walls of similar size. Frequently, outriggers also serve as dedicated mechanical levels for the building. They may also be aesthetically expressed on the building façade. Perimeter columns that engage with the outriggers may need to increase in size to account for their interaction with lateral forces. Building structures of this type can reach heights of 60 floors or more.

For further information on the design of building cores to accommodate mechanical and circulation systems, see pages 196–198.



BRACED FRAME CORE WITH OUTRIGGERS

EXTERIOR STRUCTURES AND OTHER CONFIGURATIONS

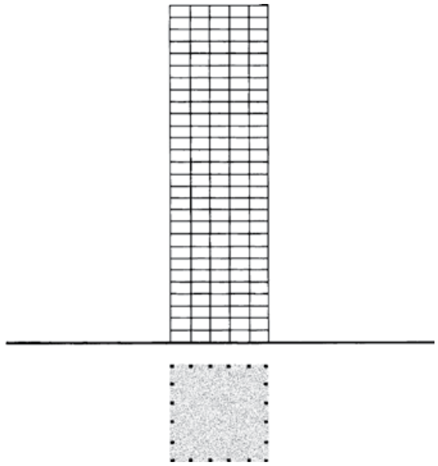
Many of the world's tallest buildings are designed as *exterior structures*, a configuration in which lateral force–resisting elements are arranged around the perimeter of the building structure. Compared to core structures, dispersing these elements to the outer edges of the structure allows them to act over a greater area, thereby increasing their efficiency. Configurations of this type can also minimize physical space restrictions within the building interior.

The most common exterior structure configuration is the *tube structure*. Either rigid framed column-and-beam assemblies or braced frame diagonal members, of steel and/or concrete, are deployed continuously around the building perimeter, thereby creating a strong and stiff hollow tube.

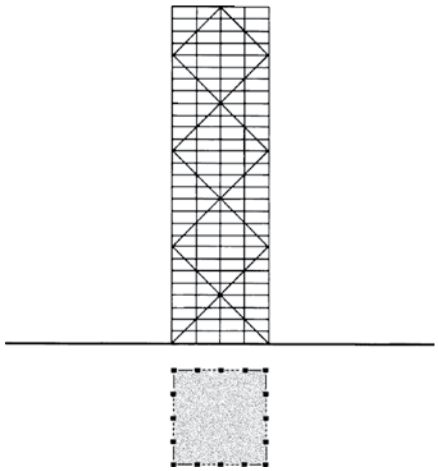
When rigid frames are used in tube structures, beams must be deeper and columns may need to be larger or more closely spaced than would otherwise be required. When constructed in steel, the moment-resisting column-to-beam joints are more costly to construct, although systems of off-site prefabrication can minimize this disadvantage. As with core structures, the performance of rigid frame tubes can be enhanced with the integration of hat or belt trusses.

Braced frame tubes are highly structurally efficient. When constructed in steel, these structures also rely on simpler, more easily assembled connections between columns and beams in comparison to rigid frame tubes. The diagonal braces that are an integral part of this system often have a strong impact on the appearance of the building façade.

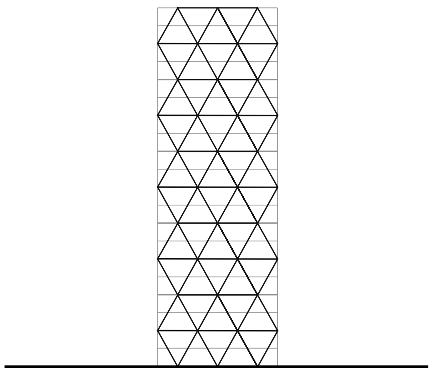
Other exterior structure forms include tube-in-tube, in which structural interaction is created between perimeter and core elements; bundled tubes, which allow more variation in building massing; diagrids, in which latticed frameworks carry both vertical and lateral loads with few or no vertical columns; and space trusses, structures similar to braced frame tubes but with the addition of large-scale diagonals that pass through the building interior.



RIGID FRAME TUBE



BRACED FRAME TUBE



DIAGRID

PRACTICAL LIMITS ON THE HEIGHT AND SLENDERNESS OF TALL BUILDINGS

At the time of this writing, the world's tallest building is Dubai's Burj Khalifa Tower, with 163 occupied floors and a height of 2717 ft (828 m). For most of its height, it is constructed as a sitecast concrete flat plate wall-and-slab structure. Lateral stability is provided by a central concrete core buttressed by heavy shear walls radiating toward the tower extremities. This *buttressed core* design is considered practical for buildings 1 mile (1.6 km) tall or greater.

As a building becomes increasingly tall and thin, the challenges of maintaining lateral stability multiply. Typical tall commercial and mixed-use buildings have *slenderness ratios* (ratio of height to least plan dimension at the base) in the range of 5 to 10. For example, the Burj Kalifa is 9 times as tall as it is wide at its base. On constrained, high-value urban sites, residential towers with slenderness ratios of 15 or higher have been constructed. The 111 West 57th Street residential tower in New York City is one of the world's most slender tall buildings, approximately 1440 ft (440 m) in height and 23 times as tall as it is wide.

SPECIAL CONSIDERATIONS IN THE DESIGN OF TALL STRUCTURES

Steel and Concrete Structural Systems

Both steel and concrete are well-suited for use in tall building structures. Steel is light in weight and ductile. A lightweight building frame minimizes the amount of structure and foundation required to support its own weight, while a ductile structural frame can readily absorb the high stresses and dynamic energy imparted into it by the forces of wind or earthquake.

Modern concrete, made with high-strength mixes and reinforced to impart ductility into this otherwise brittle material, can be used to construct building frames that are also strong, stiff, and resilient. Concrete is especially resistant to impact or blast and, unlike steel, usually does not require added protection from the heat of building fires. The high stiffness of concrete shear walls allows the design of compact stabilizing systems and slender structures.

The optimal choice of structural material also varies geographically. The availability and cost of steel and concrete differ from one region of the globe to another, as does the availability of tradespersons experienced in working with either of these materials.

Steel and concrete can also be combined in ways that exploit the attributes of each material. Composite columns made of steel box shapes filled with high-strength concrete can achieve very high load-carrying capacity. For example, the composite "supercolumns" in Taiwan's Taipei 101 building measure almost 8 × 10 ft (2.4 × 3.0 m) in section at their bases. Similarly, shear walls constructed of pairs of heavy steel plates filled with concrete between can be used to create very strong, stiff, and resilient core structures that are also easier and faster to build than shear walls constructed from concrete conventionally reinforced with internal steel reinforcing bars.

Damping Mechanisms for Resisting Lateral Forces

A tall building structure's response to the effects of wind or earthquake can be enhanced with devices designed to dampen the movements imparted to it by these loads. *Viscous dampers* are shock-absorber-like devices incorporated into parts of the building frame such that they reduce building deflections during high lateral loading as well as increase the structure's energy-absorbing capacity.

Viscous dampers may also be combined with *base isolators* at the foundation of a building, allowing a degree of separation between the building structure and the ground upon which it rests. In the event of an earthquake, a significant portion of the ground motion is never transmitted into the building structure at all. Meanwhile, the dampers act to prevent the structure from drifting beyond the physical limits of the isolation system. In severe earthquake zones, base isolation systems accommodating displacements of up to 30 in. (760 mm) or more may be used. Where base isolation is employed, allowance must be made for the expected displacements between the building and the adjacent ground. Utility lines require flexible connections where they enter the foundation. Connections to exterior stairs, plazas, sidewalks, and adjacent buildings must also be able to accommodate the differential movements that may occur.

Tuned mass dampers may be used to control deflection or *side sway* in tall buildings. These are heavy masses, suspended, pendulum-like, within the building structure, usually near its top, and connected to it by an array of dampers similar to those discussed above. As wind forces act to deflect the structure sideways, the inertia of the suspended mass resists these movements and reduces their magnitude. *Tuned liquid dampers* consisting of water tanks with specially configured internal chambers and baffles can be designed to work in a similar manner. The water stored in these tanks can also serve as emergency supply for the building's fire suppression systems.

Active dampers rely on sensors placed near the top of the building structure that measure accelerations in real time. This information is processed and then used to command hydraulic activators that exert counteracting forces on portions of the structure, thereby lessening movements.

Such dampening systems can be especially helpful in very tall or slender buildings where the discomfort caused by building sway frequently becomes the controlling factor in the structural design. By reducing lateral deflections and lessening accelerations, these systems achieve the required structural performance and occupant comfort in structures of less weight and lower cost.

3
SIZING THE STRUCTURAL SYSTEM

This section will assist you in assigning approximate sizes to structural elements. Additional information on design and building with each structural system is also provided.

WOOD LIGHT FRAME CONSTRUCTION

Wood Light Frame Construction uses relatively slender, closely spaced members to form walls, floors, and roofs in a system also called *platform frame construction*. It is an economical and flexible building system used extensively for single family homes as well as low-rise residential and commercial structures.

This system is largely fabricated on-site and individual framing members are small. Where economy is a primary concern, the use of a 2- or 4-ft (600- or 1200-mm) modular dimension will reduce waste. Wood Light Frame Construction easily and unobtrusively incorporates mechanical systems and other building services into its concealed framing cavities. Because of its relatively low resistance to fire, Wood Light Frame Construction is the most restricted in height and area of all Construction Types regulated by the model building codes.

Wood Light Frame Construction is a wall and slab system. Lateral bracing is usually provided by shear walls. Information on the components of Wood Light Frame Construction can be found on pages 58–65.

HEAVY TIMBER AND MASS TIMBER CONSTRUCTION

Heavy Timber Construction uses thicker wood members configured as a post and beam system. This type of construction has higher load capacity than wood light framing, greater fire resistance than unprotected steel, and the unique aesthetic qualities of its exposed wood components. It may be constructed with members of solid wood, glue-laminated wood, or other engineered lumber products. This system is used for both residential construction and low-rise commercial and industrial buildings.

Heavy timber post and beam frames may be stabilized laterally by the shear resistance of the walls or panels used to enclose the frame, or with diagonal bracing. When wood is combined with concrete or masonry construction, walls made of those materials can act as shear walls as well.

Mass Timber Construction uses prefabricated, large-format wood panel products, such as cross-laminated timber (CLT). These panels may be configured as wall and slab systems or used in combination with heavy timber post and beam framing. Like heavy timber members, the thickness of mass timber panels affords natural fire resistance, and with added fire-resistant coverings, fire-resistance ratings as high as 3 hours can be achieved. In low-rise structures, mass timber panels can act as shear walls. In taller structures, concrete shear walls or braced frames of heavy timber or steel are most common.

Modern heavy timber and mass timber systems utilize significant off-site prefabrication to reduce the time required for construction on-site. Because of the absence of hollow concealed spaces in these systems, arranging mechanical and electrical systems requires extra care. Larger components, such as ductwork or plumbing, must either be exposed to the interior or concealed behind separately installed finishes.

Information on the components of Heavy Timber and Mass Timber Construction can be found on pages 66–79. For more information about how the model building codes treat heavy timber and mass timber systems, see pages 388–390.

WOOD AND MASONRY CONSTRUCTION

Both Wood Light Frame and Heavy Timber Construction can be combined with masonry construction to create structural systems with increased fire resistance or higher load capacity. These hybrid systems are described under Masonry Structural Systems, beginning on page 81.

TALL WOOD BUILDINGS

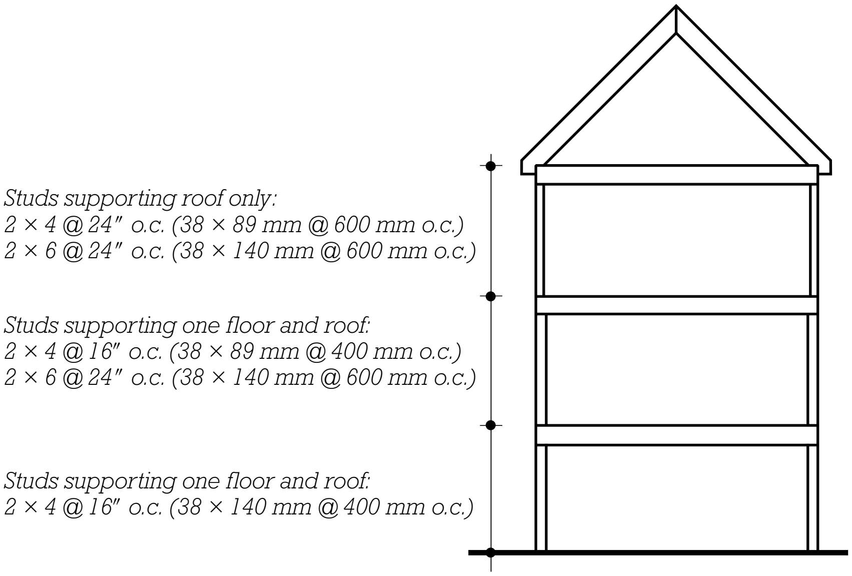
The International Building Code prescriptively limits heavy timber and mass timber building heights to between 3 and 18 stories, depending on the building occupancy and level of fire protection provided. The 2020 edition of the National Building Code of Canada permits mass timber buildings as tall as 12 stories for some occupancies. For more information about building code requirements for mass timber construction, see pages 388–390.

Both codes also allow tall mass timber buildings to be approved on a performance (rather than prescriptive) basis. For example, one of the world's tallest mass timber buildings is the Brock Commons, located in Vancouver, British Columbia. This 174-ft (53-m) residential tower consists of 17 stories of mass timber construction combined with a concrete ground-level podium and two vertical concrete cores providing lateral stability.

Tall wood structures are frequently determined to have lower carbon footprints than comparable structures of other noncombustible materials. See pages 34–35 for more information about the global warming impacts of structures.

WOOD STUD WALLS—CONVENTIONAL CONSTRUCTION

Use the diagram below to select a wood stud size and spacing for conventional low-rise wood light frame residences and buildings. For wood stud walls designed for a wider variety of loading and span conditions, use the charts on the opposite page.



ACTUAL SIZES OF WALL STUDS

Nominal Size	Actual Size
2 × 4	1½″ × 3½″ (38 × 89 mm)
2 × 6	1½″ × 5½″ (38 × 140 mm)
2 × 8	1½″ × 7¼″ (38 × 184 mm)

WOOD STRENGTH

For the charts on the opposite page, examples of strong woods include Select Structural grades of Douglas Fir-Larch, Hemlock, and Southern pine. Examples of average-strength woods include No. 2 grades of Hem-Fir or Spruce-Pine-Fir. For other species and grade combinations of intermediate strength, you may interpolate between the results charted for these two groups.

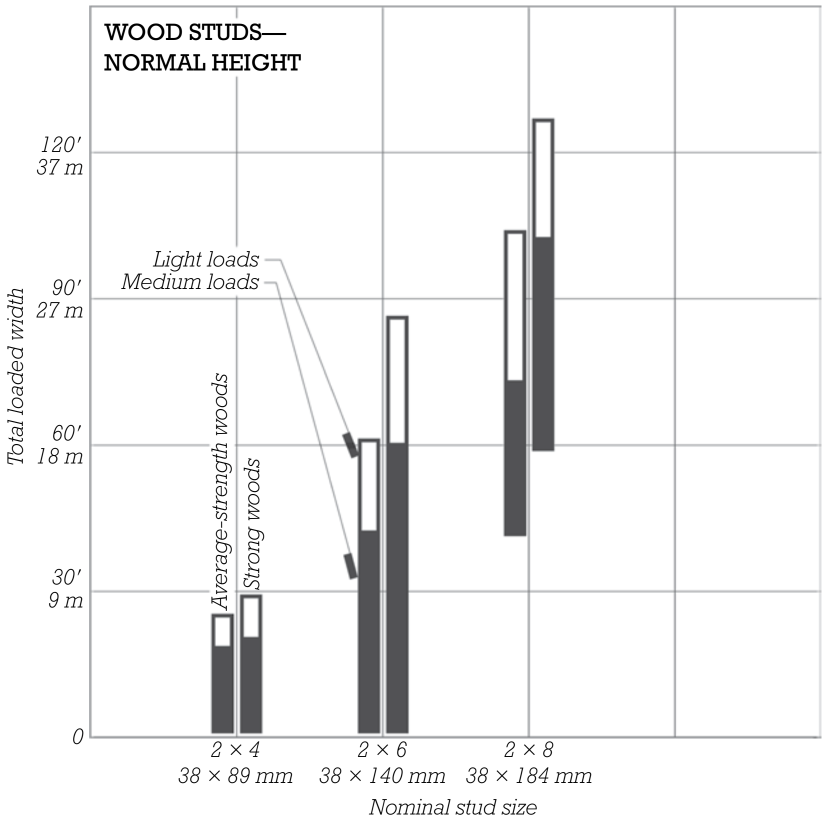
SPACING OF WALL STUDS

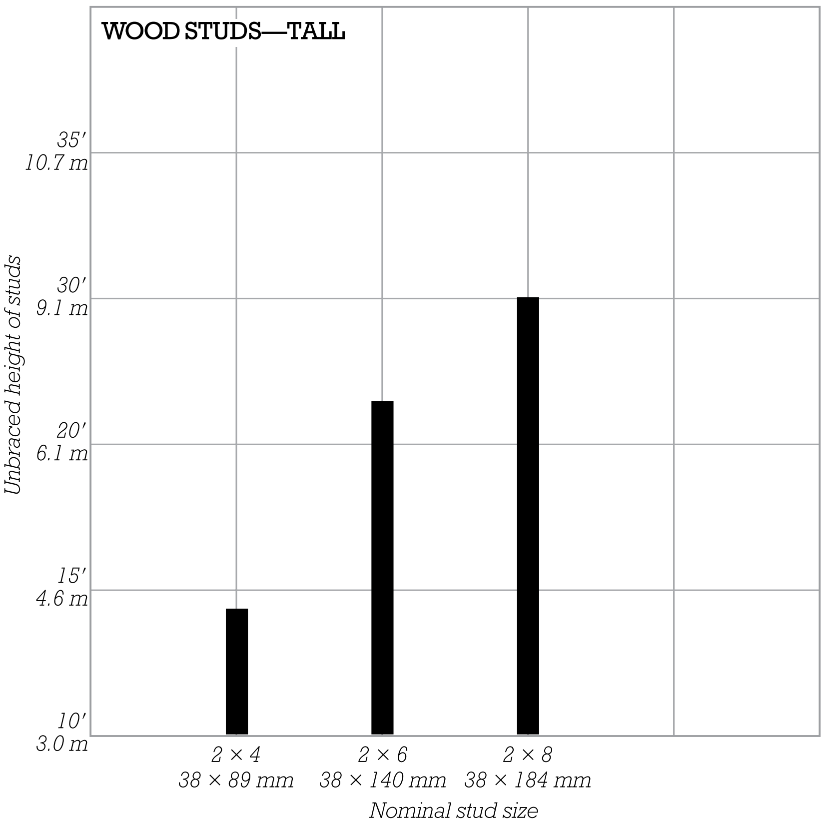
Wall studs are most commonly spaced at 16 or 24 in. (400 or 600 mm) on center. A 12-in. (300-mm) spacing may be used where greater loads must be supported. Studs should always be spaced within a 4-ft (1200-mm) module in order to coordinate with the standard width of various sheathing and wallboard products that are commonly used with this type of construction.

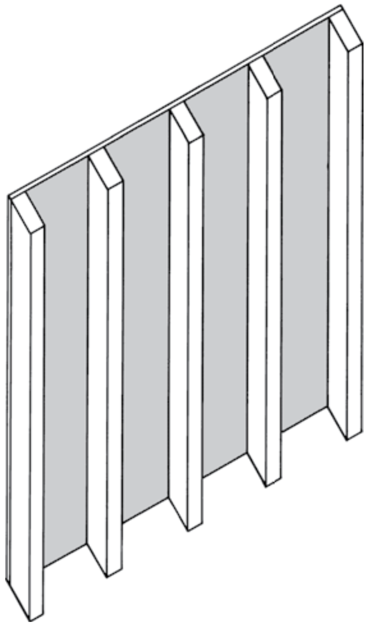
FIRE RESISTANCE AND WOOD STUDS

Wood stud walls may be used in Wood Light Frame Construction and Ordinary Construction. Framing covered with one layer of ⅝-in. (16-mm) Type X gypsum board or its equivalent on each side can achieve a 1-hour fire-resistance rating. With two layers on each side, a 2-hour rating can be achieved.

WOOD STUD WALLS







The top chart is for loadbearing wood stud walls up to 10 ft (3.0 m) in height. For each nominal stud size, read from the right-hand bar for strong woods or from the left-hand bar for average-strength woods. Read in the top open areas for light loads, or in the lower solid areas for medium loads. *Total loaded width* is the tributary width of one floor (one-half of its span) multiplied by the number of floors and the roof above the wall.

For stud walls taller than 10 ft (3.0 m), read from both charts on this page, using the larger size indicated by either chart. *Unbraced height of studs* is the vertical distance between floors or other supports that brace the studs laterally against buckling.

■ On the lower chart, for strong woods, light loads, and close stud spacing, read toward the top in the indicated areas. For average-strength woods, heavy loads, and greater stud spacing, read toward the bottom.

■ Wall height may be increased with the addition of intermediate bracing perpendicular to the wall plane.

ACTUAL SIZES OF FLOOR JOISTS

For the actual size of solid wood joists, read from the following table. I-joists are listed in actual size.

Nominal Size	Actual Size
2 × 6	1½″ × 5½″ (38 × 140 mm)
2 × 8	1½″ × 7¼″ (38 × 184 mm)
2 × 10	1½″ × 9¼″ (38 × 235 mm)
2 × 12	1½″ × 11¼″ (38 × 286 mm)

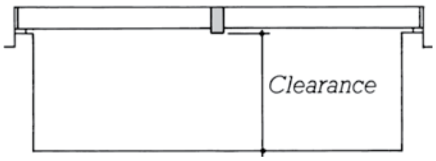
TOTAL FINISHED FLOOR THICKNESS

To estimate total finished floor thickness, add 2 to 3 in. (50 to 75 mm) to the actual joist size to account for conventional subflooring and finish materials.

BEAMS SUPPORTING FLOOR FRAMING

Wood Beams

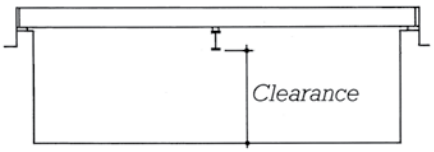
For sizing wood beams, see the chart on page 71. To determine clearance under a wood beam, assume that the top of the beam is level with the top of the floor joists.



JOISTS WITH WOOD FLOOR BEAM

Steel Beams

Beam Size	Approximate Depth of Beam	Span of Beam
W8	8″ (205 mm)	8′–13′ (2.4–4.0 m)
W10	10″ (255 mm)	10′–16′ (3.0–4.9 m)
W12	12″ (305 mm)	12′–18′ (3.7–5.5 m)



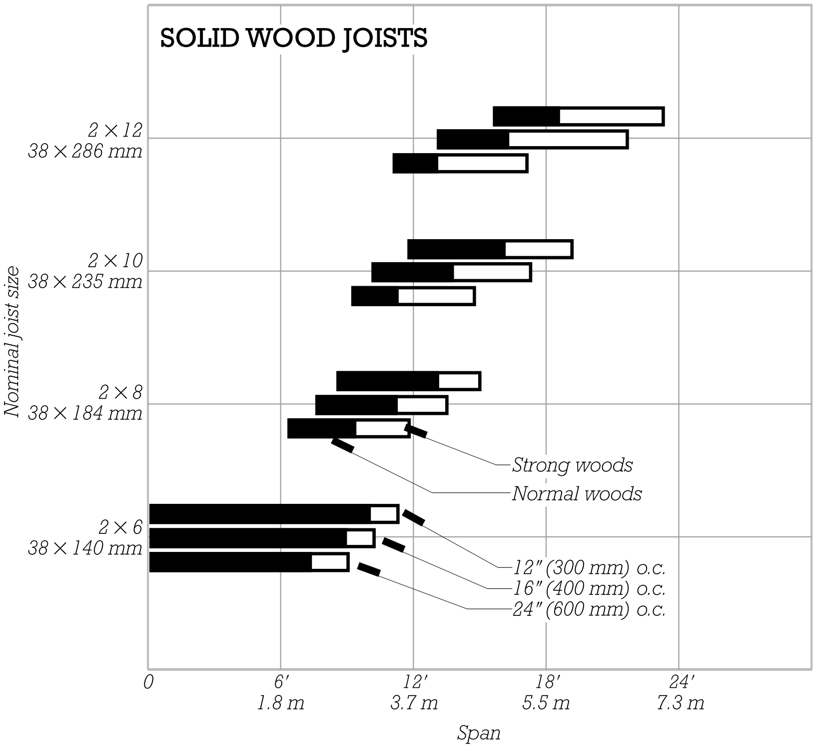
JOISTS WITH STEEL FLOOR BEAM

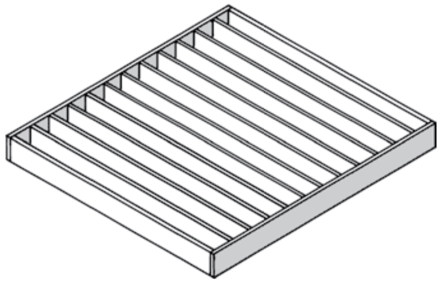
For lightly loaded beams, use the longer spans indicated. For heavily loaded beams, use the shorter spans. To determine clearance under a steel beam, assume that the top of the beam is level with the top of the foundation wall.

FIRE RESISTANCE AND WOOD LIGHT FRAME JOISTS

Wood floor joists may be used in Wood Light Frame Construction and Ordinary Construction. Floor/ceiling assemblies framed with solid wood joists and nominal 1-in. (19-mm) subflooring and finish flooring can achieve a 1-hour fire-resistance rating when the underside of the framing is finished with one to two layers of Type X gypsum board or its equivalent. With I-joist framing, ⅝-in. (16-mm) furring channels may also be required. A 2-hour rating can be achieved with solid or I-joist framing with two layers of ⅝-in. (16-mm) Type X gypsum board and ⅝-in. (16-mm) furring channels.

WOOD FLOOR JOISTS

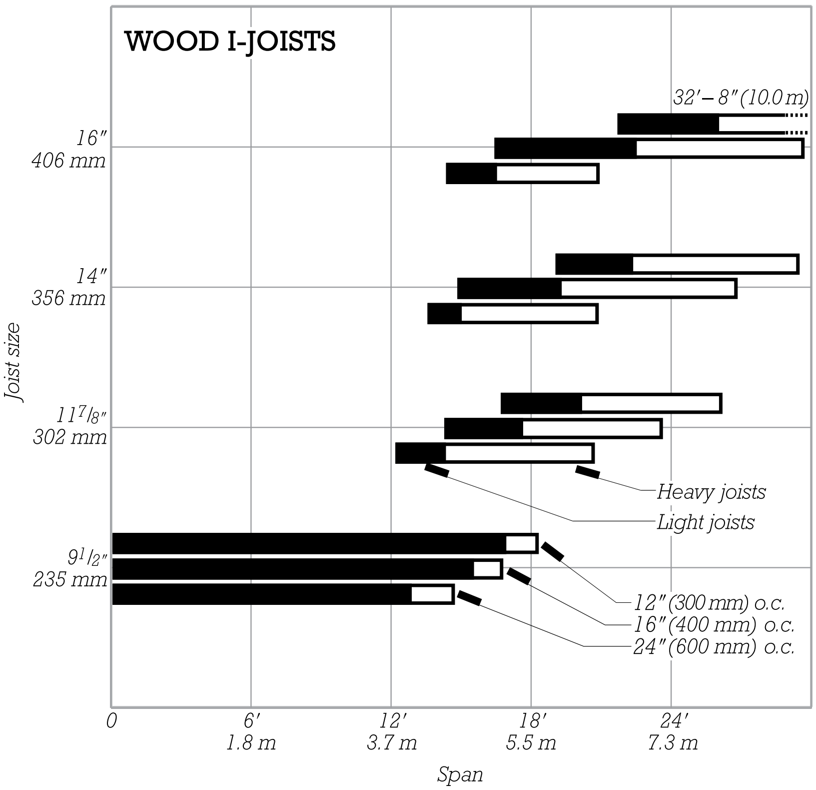




The top chart is for solid wood floor joists with residential floor loads. For joists supporting only attic loads, decrease the indicated size by one or two sizes. For larger loads, increase the indicated joist size by one or two sizes.

■ Read from the top, middle, or bottom bars for 12-in., 16-in., or 24-in. (300-, 400-, or 600-mm) joist spacings, respectively.

■ Read in the open bar areas for strong woods, such as Douglas Fir-Larch, Southern pine, and Oak. Read in the solid bar areas for average-strength woods.



The bottom chart is for wood I-joists with residential floor loads. For joists supporting only attic loads, decrease the indicated size by one or two sizes. For larger loads, increase the indicated joist size by one or two sizes.

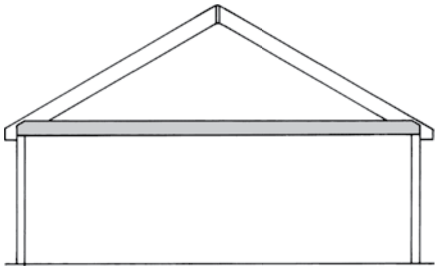
■ Read from the top, middle, or bottom bars for 12-in., 16-in., or 24-in.(300-, 400-, or 600-mm) joist spacings, respectively.

■ Read in the open bar areas for heavy- and medium-weight I-joists. Read in the solid bar areas for light-weight I-joists.

ACTUAL SIZES OF ROOF RAFTERS

For the actual size of solid wood rafters, read from the following table. I-joists are listed in actual size.

Nominal Size	Actual Size
2 × 4	1½″ × 3½″ (38 × 89 mm)
2 × 6	1½″ × 5½″ (38 × 140 mm)
2 × 8	1½″ × 7¼″ (38 × 184 mm)
2 × 10	1½″ × 9¼″ (38 × 235 mm)

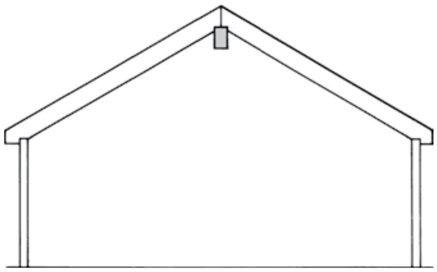


RAFTERS WITH RAFTER TIES

TIES OR BEAMS SUPPORTING ROOF RAFTERS

Rafter ties connecting rafters at their bases may be sized either as floor joists, if they are intended to support habitable space, or as ceiling joists, if they are supporting attic loads only. See pages 60–63.

Structural ridge beams can eliminate the need for ties at the base of the rafters. See pages 70–73 for sizing wood beams.

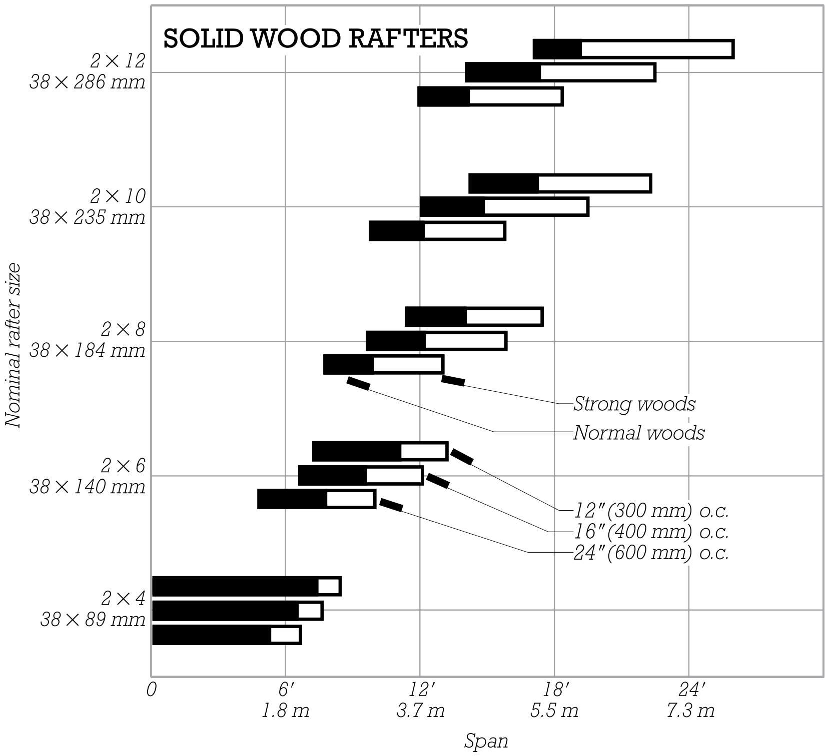


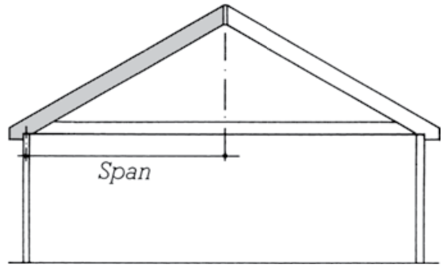
RAFTERS WITH RIDGE BEAM

FIRE RESISTANCE AND WOOD LIGHT FRAME RAFTERS

Wood roof rafters may be used in Wood Light Frame Construction and Ordinary Construction. A 1-hour fire-resistance rating can be achieved with two layers of ⅝-in. (16-mm) Type X gypsum board or its equivalent applied to the underside of the framing.

WOOD ROOF RAFTERS

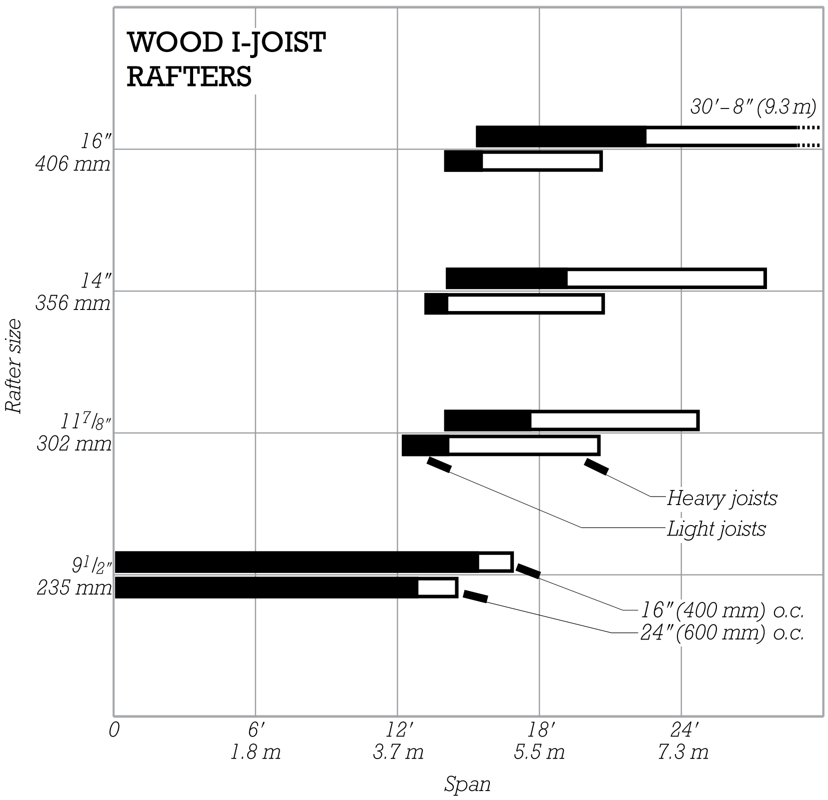




The top chart is for solid wood roof rafters with moderate snow loads (see page 32). For roofs without snow loads, decrease the indicated rafter size by one size. For roofs in heavy snow-load areas, increase the rafter size by one or more sizes.

■ Read from the top, middle, or bottom bars for 12-in., 16-in., or 24-in. (300-, 400-, or 600-mm) rafter spacings, respectively.

■ Read in the open bar areas for strong woods, such as Douglas Fir-Larch, Southern pine, and Oak. Read in the solid bar areas for average-strength woods.



The bottom chart is for I-joist roof rafters with moderate snow loads (see page 32). For roofs without snow loads, decrease the indicated rafter size by one size. For roofs in heavy snow-load areas, increase the rafter size by one or more sizes.

■ Read from the top or bottom bars for 16-in. or 24-in. (400- or 600-mm) rafter spacings, respectively.

■ Read in the open bar areas for heavy- and medium-weight I-joists. Read in the solid bar areas for light-weight I-joists.

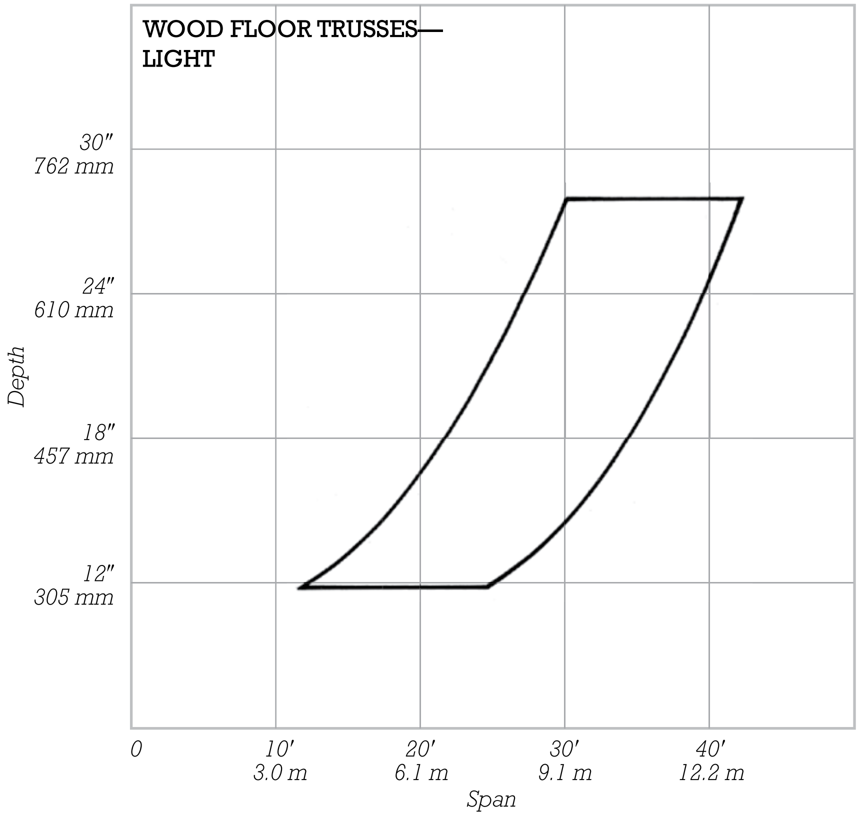
WOOD FLOOR AND ROOF TRUSSES—LIGHT

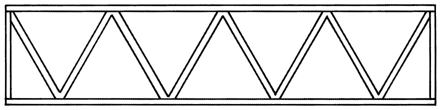
Wood floor and roof trusses can easily be used in place of conventional wood joists and rafters in Wood Light Frame Construction. These prefabricated elements permit quicker erection in the field and greater clear spans. They require fewer interior loadbearing walls and permit easy running of electrical and mechanical services through the open spaces within the trusses.

FIRE RESISTANCE AND WOOD TRUSSES

Wood trusses may be used in Wood Light Frame Construction and Ordinary Construction. They can have a 1-hour fire-resistance rating when covered with nominal 1-in. (19-mm) subflooring and finish flooring, and when the underside of the framing is finished with one to two layers of Type X gypsum board or its equivalent. A 2-hour rating can be achieved with three layers of ⅝-in. (16-mm) Type X gypsum board and ⅝-in. (16-mm) furring channels.

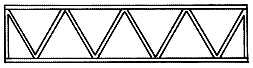
WOOD FLOOR AND ROOF TRUSSES—LIGHT



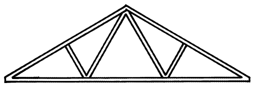


The top chart is for wood floor trusses constructed from light members up to 6 in. (140 mm) deep. For heavy loads, read toward the left in the indicated area. For light loads, read toward the right. For preliminary design, use depths in even 2-in. (50-mm) increments. Available sizes may vary with the manufacturer.

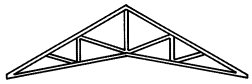
■ Typical truss spacing is 16 to 48 in. (400 to 1200 mm).



Parallel chord truss



Triangular truss



Scissors truss

The bottom chart is for wood roof trusses constructed from light members up to 6 in. (140 mm) deep. Read depths of parallel chord trusses from the left-hand scale and depths of other trusses from the right-hand scale. For heavy loads, read toward the left in the indicated areas. For light loads, read toward the right. Triangular or scissors trusses are commonly available with top chord slopes in whole number pitches from 2:12 to 7:12. Available sizes may vary with the manufacturer.

■ Typical truss spacing is 16 to 48 in. (400 to 1200 mm).

WOOD STRENGTH

For the charts on the facing page, strong woods include Select Structural grades of Douglas Fir-Larch, Hemlock, and Southern pine. Average-strength woods include No. 2 grades of Hem-Fir and Spruce-Pine-Fir. For other species and grade combinations of intermediate strength, you may interpolate between the results charted for these two groups. Engineered woods include glue-laminated wood and other structural wood composites, such as parallel strand lumber.

COLUMN SIZES

In the chart on the facing page, column sizes listed in inches are nominal size. For solid wood columns, actual size is ½ in. (51 mm) less than nominal. Metric sizes in the chart are actual size. Engineered lumber columns are specified in actual, rather than nominal, sizes. Readily available sizes vary with the product type and manufacturer, but generally range from approximately 3 in. × 5 in. (76 to 127 mm) to 9 in. × 12 in. (229 to 305 mm).

To read the chart for rectangular columns, find the rectangular area of the column and read the chart using the square size that is closest in area, or interpolate between the two square sizes closest in area.

FIRE RESISTANCE AND WOOD COLUMNS

Wood columns may be used in any Combustible Construction Type.

In Heavy Timber and Mass Timber Construction, minimum sizes for wood columns range from nominal 6 × 8 (140 × 191 mm actual) to 10 × 10 (224 × 224 mm), depending on construction type, exposure to fire, and other factors. For preliminary purposes, a nominal 8 × 8 (191 × 191 mm actual) size may be used. For more information, see pages 388–390.

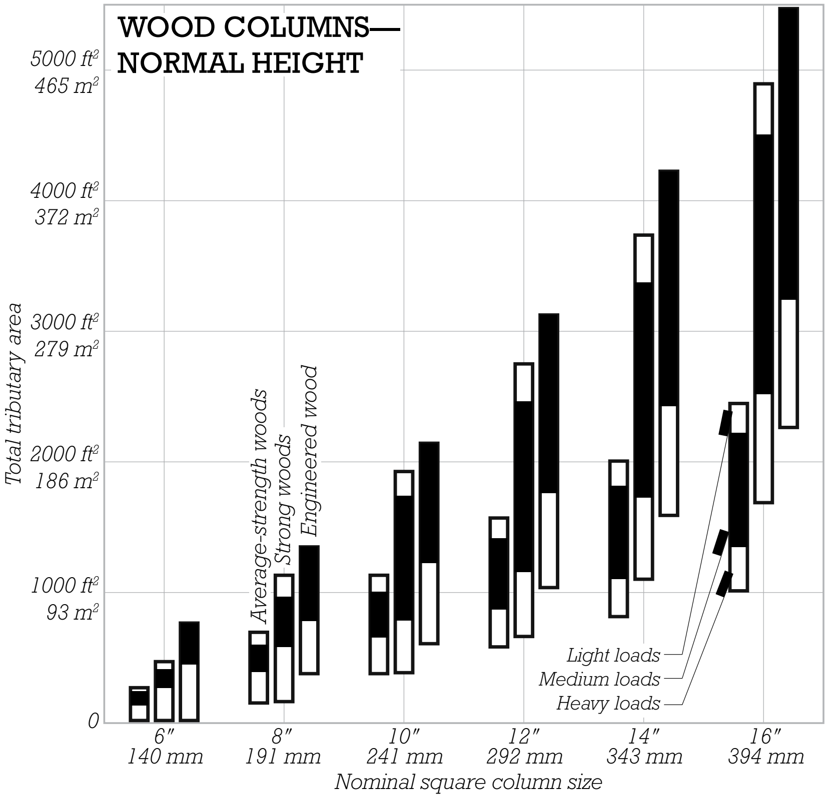
For preliminary purposes, where a wood column fire-resistance rating is required, use the following guidelines. For columns not taller than approximately 10 ft (3 m) assume that:

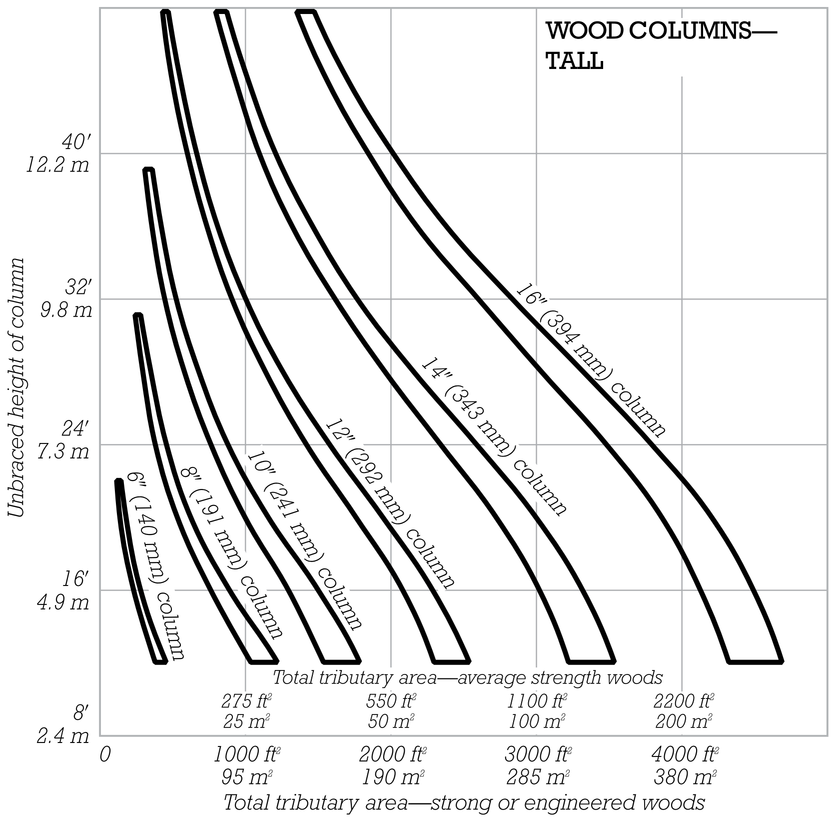
- A nominal 8 × 8 (191 × 191 mm) wood column, without added protection, can achieve a fire-resistance rating of 30 minutes.
- A nominal 8 × 8 (191 × 191 mm) wood column, with one layer of ⅝-inch (16 mm) Type X gypsum board applied to all exposed sides, can achieve a 1-hour rating.
- A nominal 10 × 10 (241 × 241 mm) wood column, without added protection, can achieve a 1-hour fire-resistance rating.
- A nominal 10 × 10 (241 × 241 mm) wood column, with two layers of ⅝-inch (16 mm) Type X gypsum board applied to all exposed sides, can achieve a 2-hour rating, and with three layers of ⅝-inch (16 mm) Type X gypsum board added to all exposed sides, a 3-hour rating.

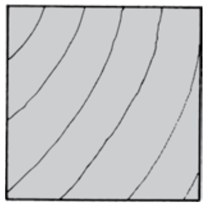
Where columns taller than 10 ft (3 m) require a fire-resistance rating, column thickness and depth may need to be increased from the guidelines listed above.

In the National Building Code of Canada, where one or more surfaces of a column must be encapsulated (protected from exposure to fire), two layers of ½-in. (12.7 mm) Type X gypsum board may be used.

WOOD COLUMNS







The top chart is for wood columns up to 12 ft (3.7 m) in height. For each column size, read from the left-hand bar for average-strength woods, the middle bar for strong woods, or the right-hand bar for engineered woods. See the facing page for more information about wood strength. Read in the top open area for light loads, the middle solid area for medium loads, or the lower open area for heavy loads. *Total tributary area* is the summed area of the roof and all floors supported by the column. See the facing page for more information about reading column size in this chart.

For columns taller than 12 ft (3.7 m), read from both charts on this page, using the larger column size indicated by either chart. *Unbraced height of column* is the vertical distance between floors or other supports that brace the column laterally against buckling.

■ For rectangular columns, read the lower chart using the smallest dimension of the column.

■ On the lower chart, read *Total tributary area* from the upper scale for average-strength woods or from the lower scale for strong or engineered woods.

■ Read toward the right within the indicated curves for light loads and toward the left for medium loads. For heavy loads, read the total tributary area for light loads and then divide by half.

WOOD STRENGTH

For the chart on the facing page, examples of strong woods include Douglas Fir-Larch, Hemlock, and Southern pine. Examples of average-strength woods include Hem-Fir, Spruce-Pine-Fir, and Cedar. For other species and grade combinations of intermediate strength, you may interpolate between the results charted for these two groups.

FIRE RESISTANCE AND WOOD DECKING

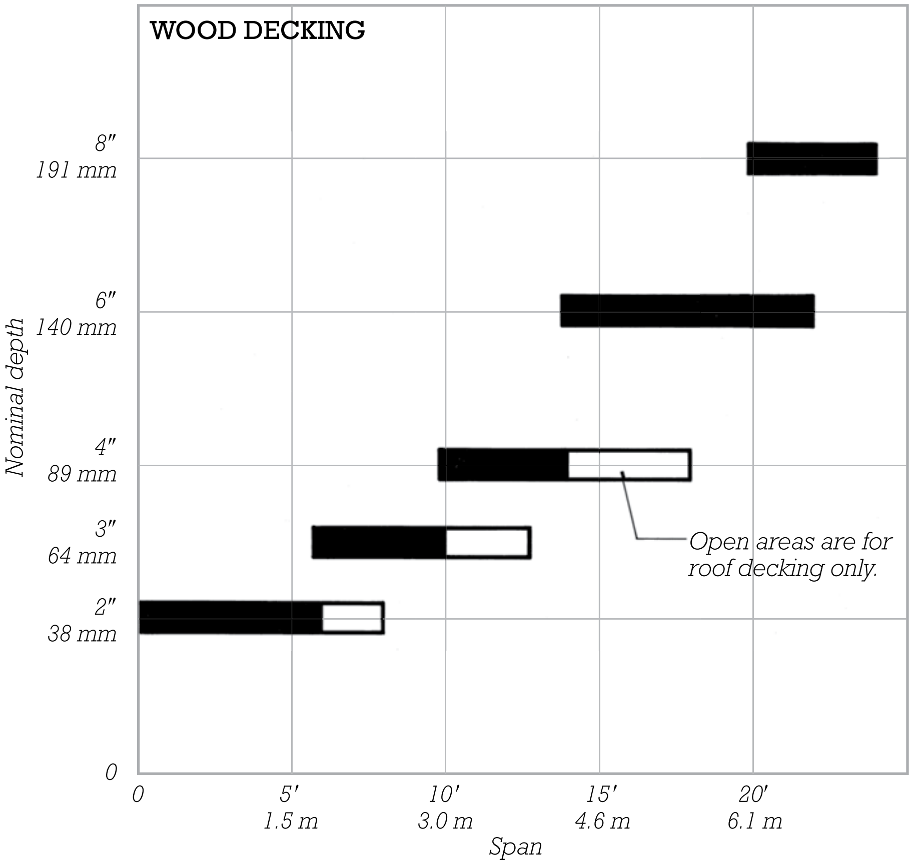
Wood decking may be used in any Combustible Construction Type.

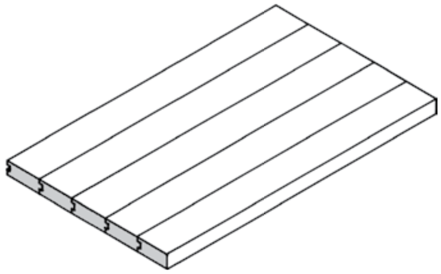
In Heavy Timber and Mass Timber Construction, the minimum wood floor decking thickness is 3 in. nominal (64 mm actual), and the minimum wood roof decking thickness is 2 to 3 in. nominal (38 to 64 mm). For more information about minimum decking sizes in both model codes, see pages 388–390.

Depending on construction type and fire-resistance requirements, the top face of wood floor decking must be covered with either wood finish materials, such as 1-in. nominal (19-mm) wood finish flooring or ½-in. nominal (13-mm) wood panel, or with 1 in. (25 mm) of concrete or gypsum topping.

For preliminary purposes, where a fire-resistance rating is required, nominal 6-in. (140-mm) decking, when unprotected, can be assumed to achieve a 1-hour rating, or, when protected on the underside with two layers of ⅝-inch (16 mm) Type X gypsum board, a 2-hour rating.

In the National Building Code of Canada, where the underside of wood decking must be encapsulated (protected from exposure to fire), two layers of ½-in. (12.7 mm) Type X gypsum board may be used.





This chart is for solid or glue-laminated wood decking. For light loads or strong woods, read toward the right in the indicated areas. For large loads or normal-strength woods, read toward the left. Read in the top open area for light loads, the middle solid area for medium loads, or the lower open area for heavy loads.

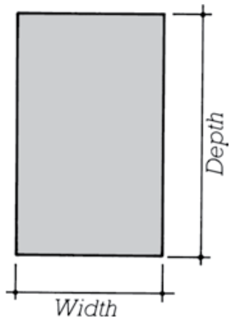
■ Decking comes in various nominal widths, 6 and 8 in. (150 and 200 mm) being the most common. The actual depth of solid wood decking is ½ in. (13 mm) less than nominal.

■ Allow approximately ¾ in. (19 mm) for the depth of finish flooring.

SIZES OF SOLID WOOD BEAMS

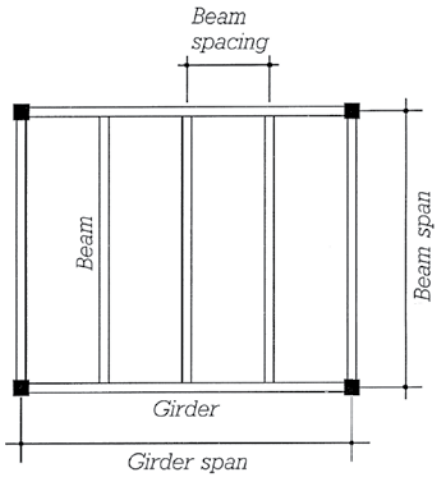
Actual depths of solid wood beams are ½ to ¾ in. less than nominal size. See the following table. Actual widths are ½ in. (13 mm) less than nominal.

Nominal Depth	Actual Depth	
4″	3½″	(89 mm)
6″	5½″	(140 mm)
8″, 10″, 12″	¾″	(19 mm) less than nominal for beam widths of 2″, 3″, and 4″, and ½″ (13 mm) less than nominal for beam widths greater than 4″
14″ or greater	½″	(13 mm) less than nominal



FRAMING FOR HEAVY TIMBER CONSTRUCTION

A Heavy Timber Framing system that uses both beams and girders allows for the greatest range of bay sizes and proportions. The beam spacing is determined by the allowable span of the floor or roof decking as tabulated on page 69. For preliminary design, limit beam and girder spans to a maximum of 20 ft (6 m) for solid wood decking, 24 ft (7.3 m) for laminated wood decking, and 32 ft (9.8 m) for cross-laminated timber decks.



HEAVY TIMBER FLOOR FRAMING

FIRE RESISTANCE AND WOOD BEAMS

Wood beams may be used in any Combustible Construction Type.

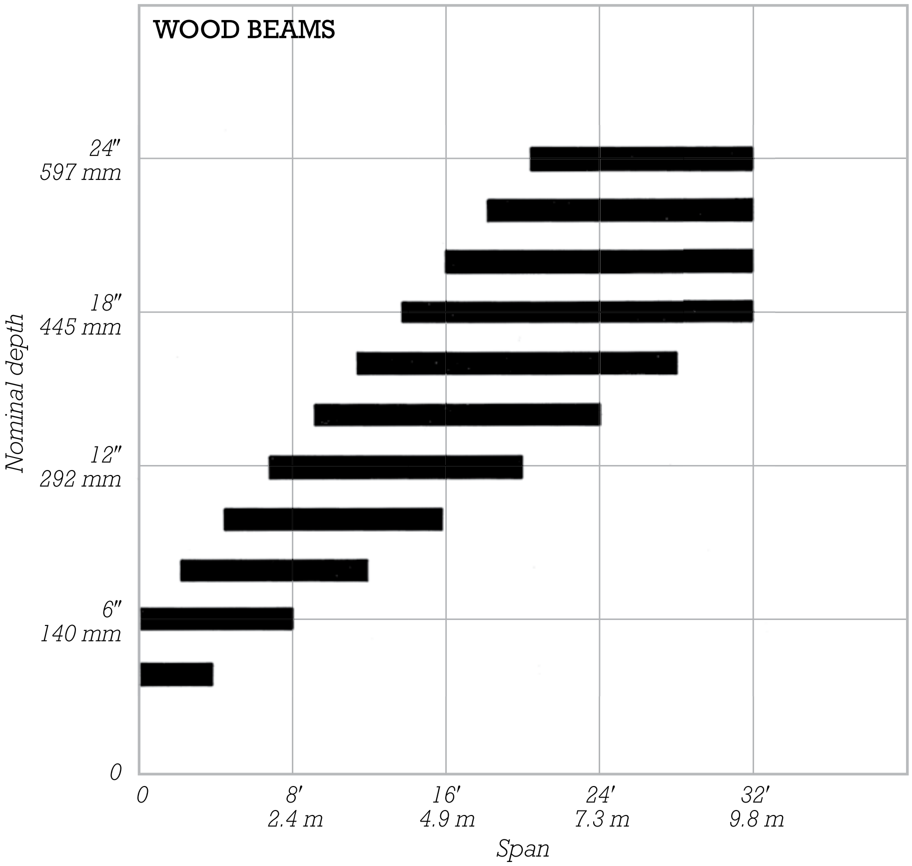
In Heavy Timber and Mass Timber Construction, minimum sizes for solid wood beams range from nominal 4 × 6 (89 × 140 mm actual) to approximately nominal 10 × 10 (224 × 224 mm actual), depending on construction type, exposure to fire, and other factors. For preliminary purposes, a nominal 6 × 10 (140 × 241 mm actual) size may be used. For more information about minimum beam sizes in both model codes, see pages 388–390.

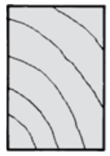
For preliminary purposes, where a wood beam fire-resistance rating is required, use the following guidelines. Starting with the beam size determined from the charts on the facing page:

- For lightly-loaded beams, a 1-hour rating may be achievable with no added protection or increase in beam size.
- For beams supporting greater loads, increase beam size by 4 in. (102 mm) in width and 2 in. (51 mm) in depth to achieve a 1-hour rating, without added protection.
- Increase beam size by 4 in. (102 mm) in width and 2 in. (51 mm) in depth and apply one layer of ⅝-in. (16-mm) Type X gypsum board to each exposed side to achieve a 2-hour rating, or apply two layers of ⅝-in. (16-mm) Type X gypsum board to each exposed side to achieve a 3-hour rating.

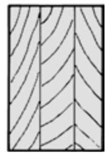
In the National Building Code of Canada, where one or more surfaces of a beam must be encapsulated (protected from exposure to fire), two layers of ½-in. (12.7 mm) Type X gypsum board (or other equivalent protection) may be used.

SOLID WOOD BEAMS





SOLID BEAM



BUILT-UP BEAM

This chart is for solid and built-up wood beams. (For engineered wood beams, see pages 72–73.) For girders or for beams carrying large loads, read toward the left in the indicated areas. For light loads or strong woods, read toward the right. For typical beam conditions, read from the middle of the indicated areas.

■ Strong woods include Douglas Fir-Larch, Southern pine, and Oak.

■ Practical widths for solid beams range from one-fourth of the depth of the beam to equal to the depth of the beam.

■ A girder should be at least 2 in. (50 mm) deeper than the beams it supports.

ENGINEERED WOOD MATERIALS

Engineered wood includes glue-laminated wood and other types of structural composite wood products. Glue-laminated wood products are manufactured from vertically stacked, glued solid lumber strips. Structural composite wood products, such as laminated strand lumber (LSL), laminated veneer lumber (LVL), and parallel strand lumber (PSL), are made from glued wood strands or veneers.

CONTINUOUS-SPAN GLUE-LAMINATED BEAMS

For greater structural efficiency, glue-laminated beams may be designed with continuous spans over multiple supports. For such beams, read toward the right in the indicated area on the chart on the facing page. Practical spans for continuous-span beam systems range from 25 to 65 ft (7.5 to 20 m).

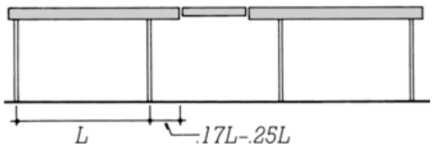
FIRE RESISTANCE AND ENGINEERED WOOD BEAMS

Engineered wood beams may be used in any Combustible Construction Type.

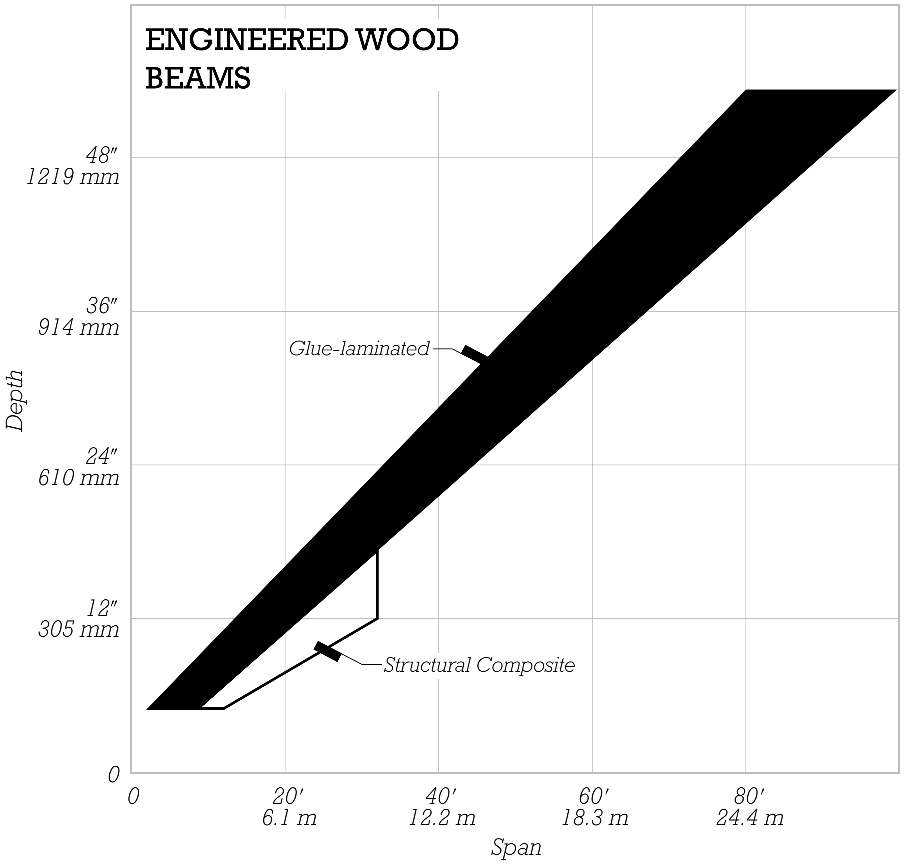
In Heavy Timber and Mass Timber Construction, minimize sizes for engineered wood beams range from approximately 3½ in. × 5½ in. (89 × 140 mm) to 9 in. × 9 in. (224 × 224 mm) in actual size, depending on construction type, exposure to fire, and other factors. For more information about engineered wood beam minimum sizes in both model codes, see pages 388–390.

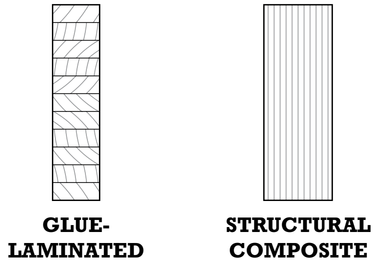
For preliminary purposes, where an engineered wood beam fire-resistance rating is required, use the following guidelines. Starting with the beam size determined from the charts on the facing page:

- For lightly-loaded beams not less than 5½ in. × 9½ in. (140 × 241 mm) in size, a 1-hour rating may be achievable with no added protection or increase in beam size.
- For beams supporting greater loads, increase beam size by 4 in. (102 mm) in width and 2 in. (51 mm) in depth to achieve a 1-hour rating, without added protection.
- Increase beam size by 4 in. (102 mm) in width and 2 in. (51 mm) in depth and apply one layer of ⅝-in. (16-mm) Type X gypsum board to each exposed side to achieve a 2-hour rating, or apply two layers of ⅝-in. (16-mm) Type X gypsum board to each exposed side to achieve a 3-hour rating.



CONTINUOUS-SPAN GLUE-LAMINATED BEAM





In the National Building Code of Canada, where one or more surfaces of a beam must be encapsulated (protected from exposure to fire), two layers of ½-in. (12.7 mm) Type X gypsum board may be used.

This chart is for engineered wood beams.

■ Typical beam spacings range from 4 ft (1.2 m) for small beams supporting decking to 24 ft (7.3 m) for larger beams supporting joists or purlins.

■ For girders, read depths from the extreme left-hand edge of the indicated area. A girder should be at least 1½ in. (38 mm) deeper than the beams it supports.

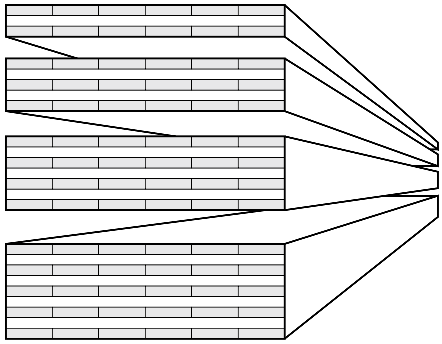
ENGINEERED WOOD BEAM SIZES

Engineered wood beams are specified by their actual size. The following table lists common sizes for both glue-laminated and structural composite wood beams.

Depths of glue-laminated wood beams are typically a multiple of 1 ⅜ in. (35 mm) or 1½ in. (38 mm), the thicknesses of laminations most used in the beam assembly. Typical widths for glue-laminated beams are one-fourth to one-seventh of the depth, rounded to the nearest standard width, as tabulated below.

Glue-Laminated Wood Beams	
Width	**Depth**
3⅛″ (79 mm)	3″–24″ (76–610 mm)
5⅛″ (130 mm)	4½″–36″ (114–914 mm)
6¾″ (171 mm)	6″–48″ (152–1219 mm)
8¾″ (222 mm)	9″–63″ (229–1600 mm)
10¾″ (273 mm)	10½″–75″ (267–1905 mm)
Structural Composite Wood Beams	
Width	**Depth**
3½″ (89 mm), 5¼″ (133 mm), 7″ (178 mm)	5½″ (140 mm), 7¼″ (184 mm), 9¼″ (235 mm), 11¼″ (286 mm), 14″ (356 mm), 16” (406 mm), 18″ (457 mm), 20″ (508 mm)

CROSS-LAMINATED TIMBER PANELS



3-layer 4 in. (102 mm) thick
5-layer 7 in. (178 mm) thick
7-layer 9 in. (229 mm) thick
9-layer 12 in. (305 mm) thick

EXAMPLE CLT PANELS

Cross-laminated timber (CLT) panels are constructed from solid lumber boards, ⅝ to 2 in. (16 to 51 mm) thick, stacked and glued in crosswise layers. Most commonly, an odd number of layers is used to ensure balanced structural behavior in the finished panel. However, even-number-layered panels are also possible.

CLTs are described by their actual dimensions. Available sizes may range from 3 to 12 in. (75 to 305 mm) in thickness, 2 to 10 ft (0.6 to 3.0 m) in width, and up to 60 ft (18 m) in length. Maximum sizes are limited by the constraints of transporting components from the factory and handling on the construction site.

After panels are laminated, but while still in the factory, openings for windows, doors, and stairs, profiling of edges where panels join, channels and cutouts for services, and other modifications are completed, using computer-automated machining. In the field, little or no additional cutting or fitting is required, and CLT erection frequently proceeds faster than alternative construction systems.

CLT panels may be assembled into wall and slab structural systems. They can also be used together with heavy timber post and beam framing, or in combination with steel, concrete, masonry, or wood light framing. CLT used in exterior walls and roofs cannot be left exposed to the elements and must be covered with appropriate materials to protect the panels and control the flow of water, heat, and air through the assembly.

FIRE RESISTANCE AND CROSS-LAMINATED TIMBER

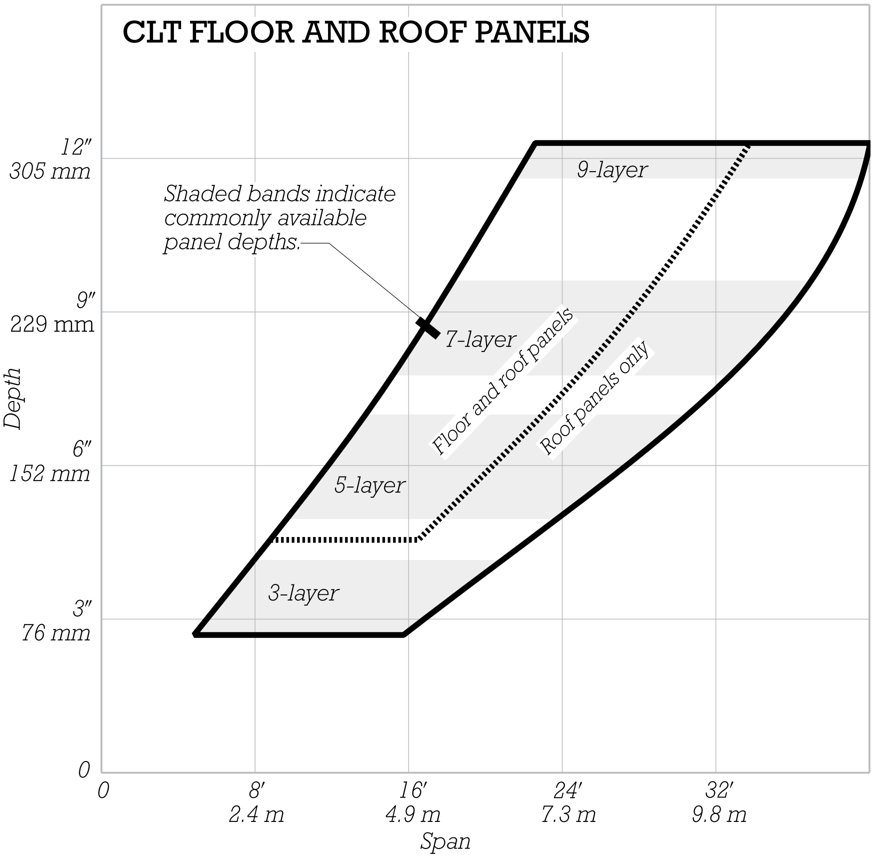
In the International Building Code, CLT floor panels and exterior wall panels must be at least 4 to 6 in. (102 to 152 mm) in thickness, and roof decks at least 3 in. (76 mm) in thickness. In the National Building Code of Canada, CLT panels must be at least 3¾ in. (96 mm) in thickness.

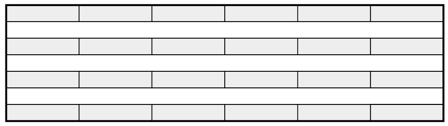
For preliminary purposes, where a CLT fire-resistance rating is required, use the following guidelines. For wall panels:

- A three-layer, 4½″ (114 mm) thick panel, without added protection, can achieve a 30-minute rating with a reduced structural load.
- A three-layer, 4½″ (114 mm) thick panel, with one layer of ⅝-inch (16 mm) Type X gypsum board applied to each side of the panel, can achieve a 1-hour rating with a reduced load.
- A five-layer, 7″ (178 mm) thick panel, without added protection, can achieve a 1-hour rating, with a reduced load.
- A five-layer, 7″ (178 mm) thick panel, with two layers of ⅝-inch (16 mm) Type X gypsum board applied to each side of the panel, can achieve a 2-hour rating, at full load.

For floor and roof panels, use the same guidelines as listed above for wall panels. Where protection is required, substitute 1 in. (51 mm) of concrete or gypsum topping for the gypsum board layers on the upward facing side of the panel. Three-layer unprotected panels should not be used in floor/roof assemblies where a fire-resistance rating is required.

CROSS-LAMINATED TIMBER





The chart at left is for cross-laminated timber floor and roof panels. For floors, use panels with five or more layers, reading from the portion of the chart labeled *Floor and roof panels*. For roof panels, read from anywhere within the indicated areas. For heavy loads, read toward the left, and for light loads, read toward the right. Shaded bands indicate ranges of the most commonly available depths and the number of laminations used in the panel build-up within each range. Consult manufacturers for actual sizes and configurations available.

CLT WALL PANELS AND BUILDING HEIGHT

	Up to 3 stories	4 or more stories
Loadbearing panels in residential buildings	3-layer	3-layer or 5-layer
Loadbearing panels in nonresidential buildings	3-layer or 5-layer	5-layer or 7-layer
Low-rise shear walls in areas subject to high seismic loads	3-layer or 5-layer	5-layer or 7-layer

Use the table at left to determine preliminary minimum thicknesses for cross-laminated timber wall panels. Use the thickest panel indicated by any of the criteria relating to building height, shear wall requirements, and fire resistance that apply to your building. Where more than one thickness is indicated for a single criterion, choose the lesser thickness for shorter panels or where panels support lighter loads, fewer floors, or smaller tributary areas. Choose the greater thickness for taller panels or when the panels support heavy loads, a greater number of floors, or larger tributary areas.

HEAVY WOOD TRUSSES

Heavy wood trusses are assembled from members at least nominal 4 × 6 (89 × 140 mm actual) in size.

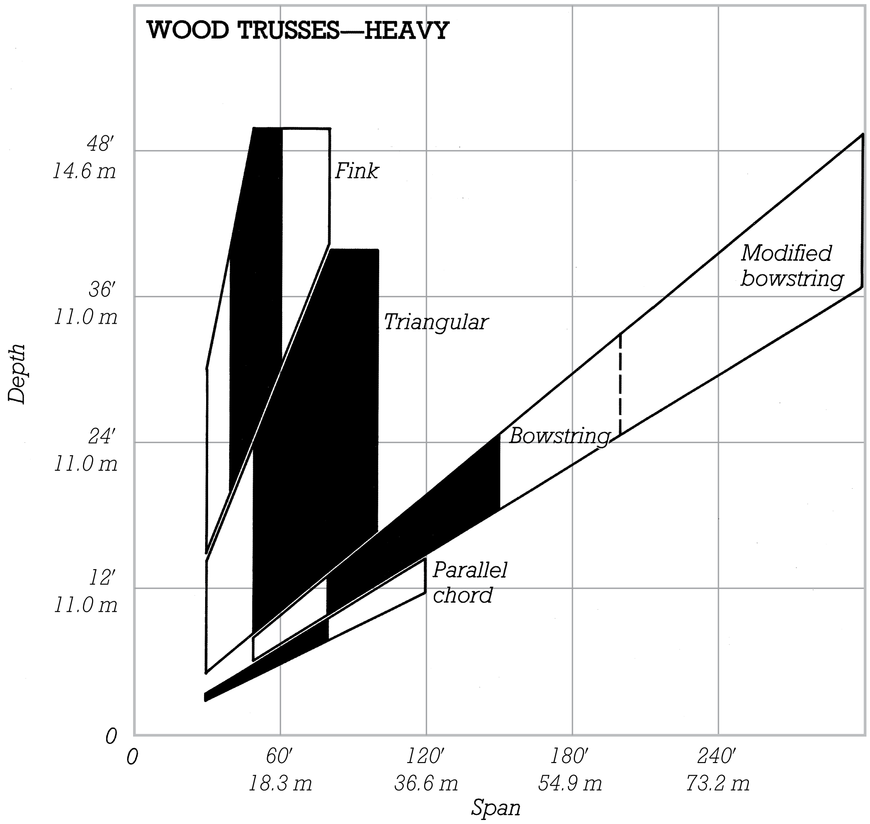
When roof trusses are spaced no more than 4 to 8 ft (1.2 to 2.4 m), wood roof decking can span directly between trusses and no additional joists or purlins are required. The maximum practical spacing of floor or roof trusses spanned by joists or purlins is approximately 20 ft (6.1 m).

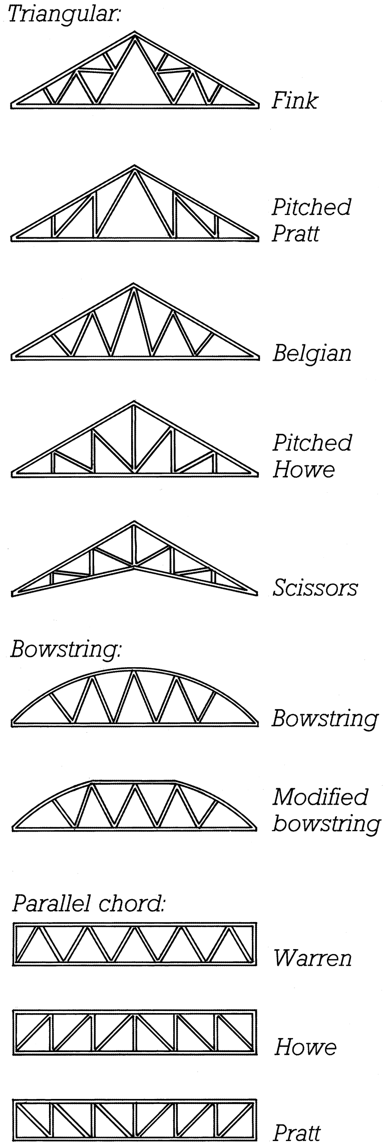
FIRE RESISTANCE AND HEAVY WOOD TRUSSES

Heavy wood trusses may be used in any Combustible Construction Type.

In Heavy Timber Construction, solid wood members of a heavy wood floor truss must be at least nominal 8 × 8 (191 × 191 mm actual), and those of a roof truss, at least nominal 4 × 6 (89 × 140 mm actual). For more information about minimum truss member sizes in both model codes see pages 388–390.

WOOD TRUSSES—HEAVY





This chart is for wood trusses.

■ The most economical span ranges for each truss type are indicated with the solid tone.

DIMENSIONS FOR POINTED ARCHES

LOW- TO MEDIUM-PITCH ARCHES (3:12 TO 8:12)

Wall Height	Thickness of Arch	Depth of Base	Depth of Crown
10″–18″ (3.0–5.5 m)	3 ⅛″, 5 ⅛″, 6¾″ (79, 130, 171 mm)	7½″–18″ for short spans (191–457 mm) 8″–30″ for medium spans (203–762 mm) 8½″–35″ for long spans (216–889 mm)	7½″–27″ (191–686 mm)

HIGH-PITCH ARCHES (10:12 TO 16:12)

Wall Height	Thickness of Arch	Depth of Base	Depth of Crown
8′–12′ (2.4–3.7 m)	5 ⅛″ (130 mm)	7½″ for short spans (191 mm) 7¾″ for medium spans (197 mm) 9½″–10″ for long spans (241–254 mm)	7¾″–24½″ (197–622 mm)

FIRE RESISTANCE AND GLUE-LAMINATED ARCHES

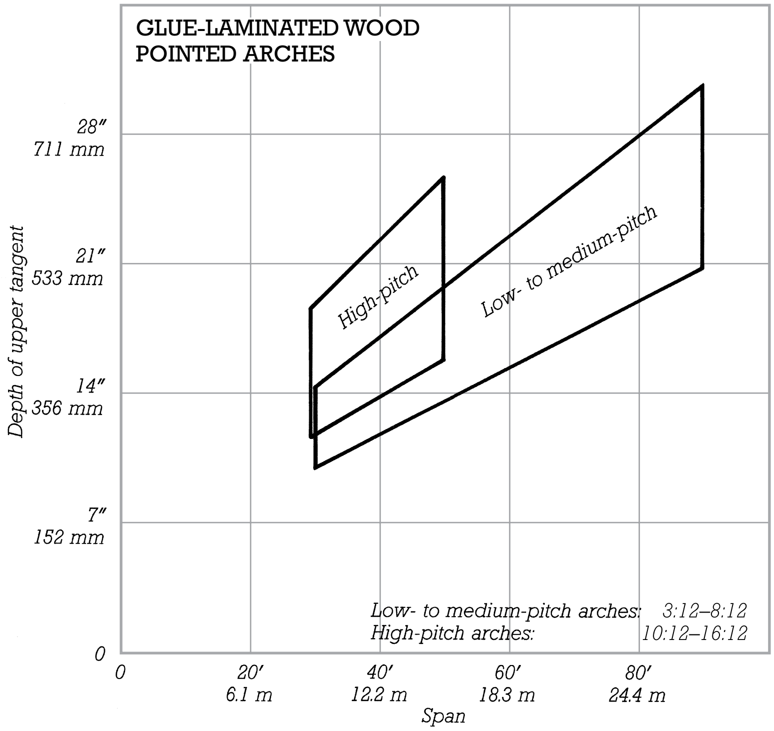
Glue-laminated wood arches may be used in any Combustible Construction Type.

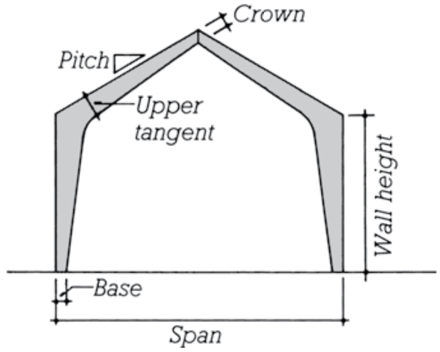
In the International Building Code, in Heavy Timber Construction or Mass Timber Construction, glue-laminated wood arches supporting floors should be no smaller than 6¾ in. × 8¼ in. (171 × 210 mm) actual size, and those supporting roofs should be no smaller than 5 in. × 8¼ in. (127 × 210 mm) for their lower halves and no smaller than 5 in. × 6 in. (127 × 152 mm) for their upper halves.

In the National Building Code of Canada, in Heavy Timber Construction, arches supporting floors should be no smaller than either 5 ⅛ in. × 9 in. (130 × 228 mm) or 6 ⅞ in. × 7½ in. (175 × 190 mm). Arches supporting roofs only should be no smaller than 5 ⅛ in. × 6 in. (130 × 152 mm) when the arch springs from the floor line, or no smaller than 3¼ in. × 6 in. (80 × 152 mm) when the arch springs from the top of a wall or abutment.

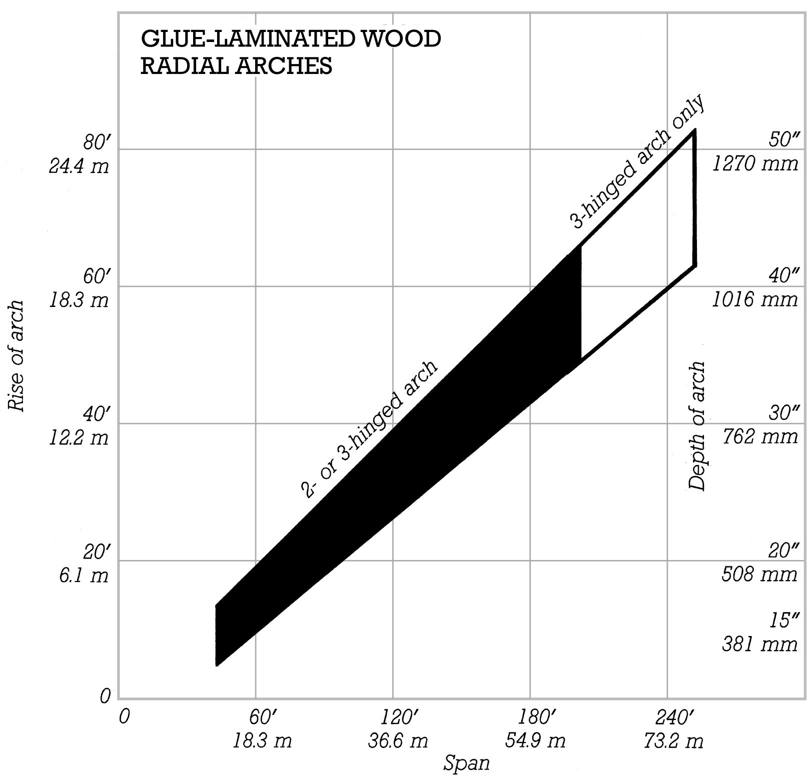
For more information on the minimum size requirements for glue-laminated wood arches in both model codes, see pages 388–390.

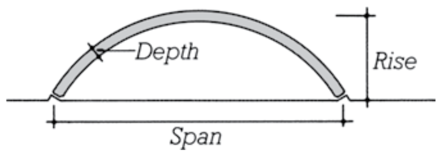
GLUE-LAMINATED WOOD ARCHES



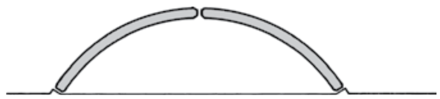


The top chart is for glue-laminated pointed arches. For low pitches, high loads, and high side walls, read toward the top in the indicated areas. For high pitches, low loads, and low side walls, read toward the bottom.





TWO-HINGE RADIAL ARCH



THREE-HINGE RADIAL ARCH

The bottom chart is for glue-laminated radial arches. Read the rise of the arch from the left-hand scale, and the depth of the arch from the right-hand scale.

■ The thickness of a radial arch should be at least one-fifth of its depth.

MASONRY STRUCTURAL SYSTEMS

Masonry construction rarely forms a complete building system on its own. Nonbearing masonry walls may be used as infill between structural columns of some other material or as a veneer applied over many other systems. Or, when loadbearing, masonry walls and columns can combine with numerous spanning systems to create complete systems.

Masonry walls may be constructed in a variety of ways. Use the following guidelines for preliminary design:

- Concrete masonry construction is generally more economical than brick because of the lower materials costs and the reduced labor required to lay the larger concrete units.
- The visual richness of brick masonry may be considered an aesthetic advantage over concrete masonry. High-quality brick masonry units are also more resistant to the effects of weather than concrete masonry units.
- Loadbearing masonry walls and columns must be steel reinforced in all but the very smallest of structures.
- For exterior walls, cavity wall construction, which includes an internal drainage plane within the wall, provides greater resistance to water penetration than solid wall construction. Cavity walls can also accommodate thermal insulation within the wall.

Since masonry construction takes place on-site and utilizes elements of small size, it is well suited for use in the construction of buildings of irregular form. Nevertheless, it is advantageous to build with modular dimensions to minimize the need for partial brick or block units. Wherever possible, use a module of one-half the nominal length of a masonry unit in plan and the height of a single unit course in elevation.

MASONRY AND WOOD CONSTRUCTION

Masonry can form the exterior, and sometimes interior, loadbearing walls for either Wood Light Frame Construction or Heavy Timber Construction, systems traditionally named *Ordinary Construction* and *Mill Construction*, respectively. Both of these systems are more fire-resistant than all-wood construction and are permitted for use in larger buildings. For more information about how the model building codes treat Ordinary and Mill Construction systems, see pages 387–388.

MASONRY AND STEEL CONSTRUCTION

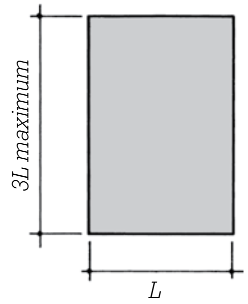
Open-web joists are the steel spanning elements most commonly used with loadbearing masonry construction because of the relatively small, concentrated loads produced by these lightweight, closely spaced elements. Where steel beams and girders bear upon masonry walls, pilasters or extra reinforcing may be required at points of support. For economy and strength, interior columns in such systems are typically structural steel rather than masonry. See pages 98–106 for information on steel construction.

MASONRY AND CONCRETE CONSTRUCTION

The sitecast and precast concrete spanning elements most commonly used with loadbearing masonry walls are shorter-span slabs without ribs or beams. These systems are often highly economical due to the minimal floor depths associated with these spanning elements, the absence of any requirement for added fire-resistive finishes, and the acoustical and energy performance of these high-mass materials. See pages 109–125 for information on sitecast concrete construction, and pages 127–137 for information on precast concrete construction.

MASONRY STRENGTH

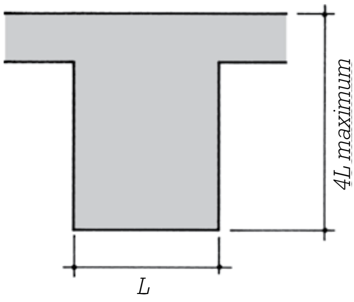
The strength and cost of brick masonry increase as stronger brick, steel reinforcing, and mortar mixes are used in its construction. When reading the top chart on the facing page, begin by assuming low-strength masonry, and read from the lower set of bars. If the wall sizes yielded by this result are impractically large, then consider using higher-strength masonry, reading from the upper set of bars or interpolating between the two sets.



RECTANGULAR COLUMNS

BRICK MASONRY COLUMN SIZES

For lightly loaded structures, the minimum size for reinforced brick masonry columns is 8 in. (200 mm) nominally on each side. For other conditions, use columns 12 in. (300 mm) square or larger. For rectangular columns, the wider side should be no more than three times the width of the narrower side. For pilasters (columns that are part of walls), the wider side should not exceed four times the width of the shorter side. For maximum economy, size brick masonry columns in increments of 4 in. (100 mm).

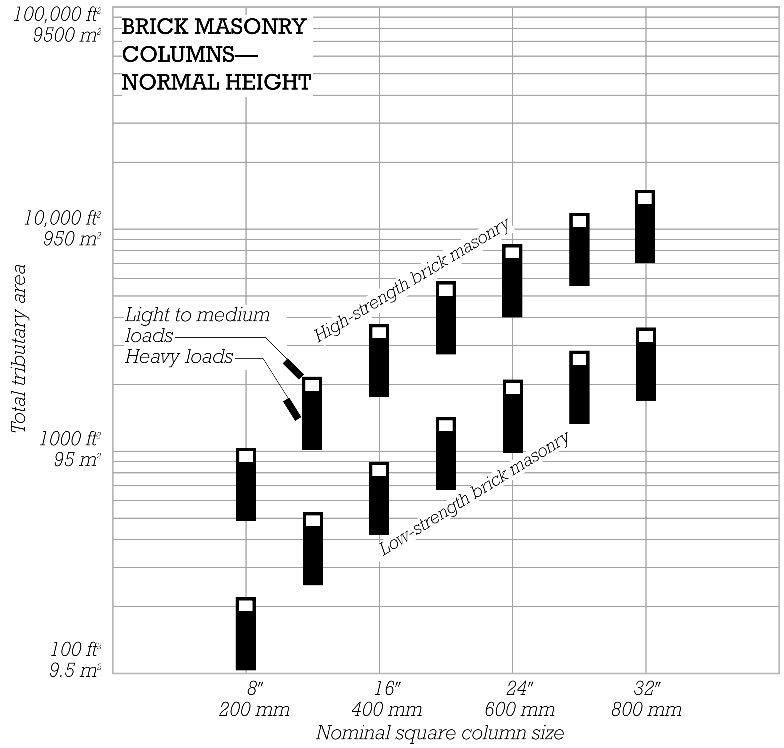


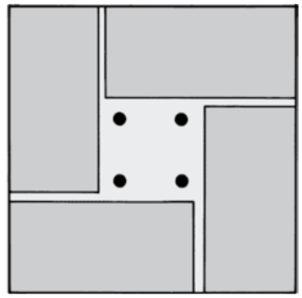
RECTANGULAR PILASTERS

FIRE RESISTANCE AND BRICK MASONRY COLUMNS

Brick masonry construction may be used in both Combustible and Noncombustible Construction. The fire resistance of brick masonry construction varies with the type of brick unit. For preliminary design, assume that a 1- to 2-hour fire-resistance rating can be achieved with an 8-in. (200-mm) square column, and a 3- to 4-hour rating can be achieved with a 10- to 12-in. (250- to 300-mm) column.

BRICK MASONRY COLUMNS





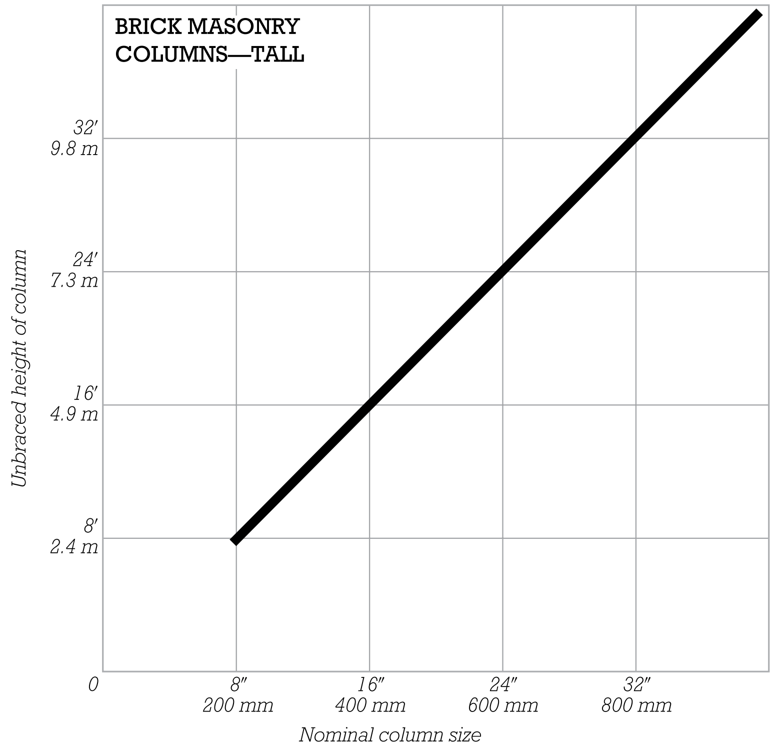
The top chart is for reinforced brick masonry columns up to 12 ft (3.7 m) tall between floors. For high-compressive-strength masonry, read from the upper set of bars. For low-strength masonry, read from the lower set. For light to medium loads, read in the upper open areas of each bar; for heavy loads, read in the lower solid areas. *Total tributary area* is the summed area of the roof and all floors supported by the column.

■ For rectangular columns, select a column of area equal to the square size indicated.

■ Actual column size is ⅜ in. (10 mm) less than nominal size.

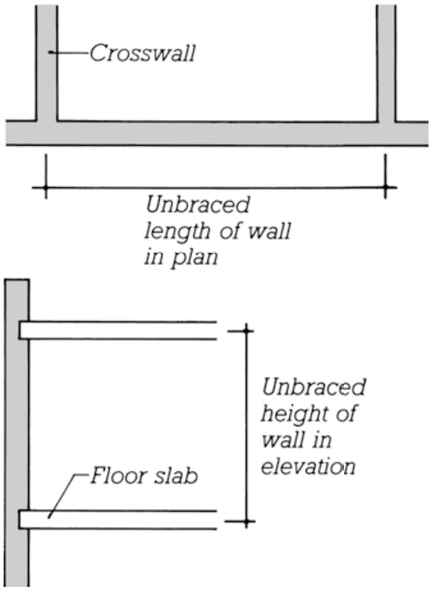
For columns taller than 12 ft (3.7 m), read from both charts on this page, using the larger size indicated by either chart. *Unbraced height of column* is the vertical distance between floors or other supports that brace the column laterally against buckling.

■ For rectangular columns, read the chart's nominal column size, using the lesser dimension of the column.



MASONRY STRENGTH

The strength and cost of brick masonry increase as stronger brick, steel reinforcing, and mortar mixes are used in its construction. When reading the top chart on the facing page, begin by assuming low-strength masonry, and read from the lower set of curves. If the wall sizes yielded by this result are impractically large, then consider using higher-strength masonry, reading from the upper set of curves or interpolating between the two sets.



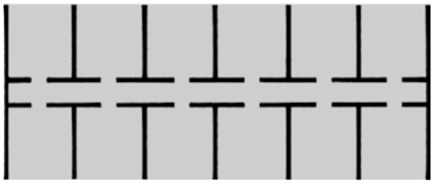
UNBRACED HEIGHT OR LENGTH OF MASONRY WALLS

MINIMUM WIDTHS OF WALLS

Reinforced brick masonry walls 6 in. (150 mm) wide should be used for one-story structures only. Use walls 8 in. (200 mm) or wider for multistory structures.

MAXIMUM UNBRACED LENGTH OF WALL

Use the bottom chart on the facing page to determine the maximum permissible unbraced length of wall in plan, in addition to its maximum permissible height. Masonry walls should be braced by crosswalls spaced at distances not exceeding those indicated on the chart. If the proposed crosswall spacing in your design is too great, either thicken the wall or add pilasters at intermediate spacing (see pages 82–83 for the sizing of pilasters).



LOW-RISE BEARING WALL CONFIGURATION *(shown in plan)*

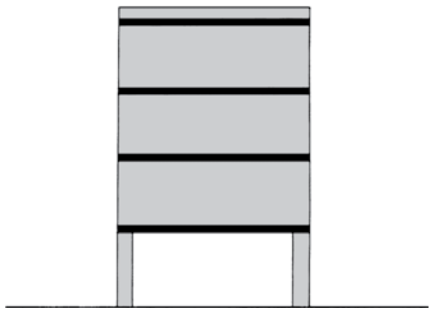
HIGH-RISE BEARING WALL CONFIGURATION *(shown in plan)*

DESIGNING WITH MASONRY BEARING WALLS

Reinforced brick masonry walls may be used in structures up to approximately 20 stories in height. In high-rise structures, the cellular arrangements of bearing walls make this system best suited to apartment buildings, hotels, dormitories, and other residential occupancies that require relatively small, repetitively arranged spaces.

For structures up to approximately six stories in height, interior crosswalls and corridor walls should be sufficient to provide the needed lateral bracing for the structure. This permits exterior walls to remain relatively open in design. At greater heights, lateral stability requirements increasingly dictate a more complete cellular configuration of walls. In this case, the sizes of openings in the exterior walls will become increasingly restricted.

Loadbearing walls should be aligned consistently from floor to floor and should be continuous from the roof to the building foundation. Where it is desirable to create a larger space on a lower floor, it may be possible to design one or more of the walls above to act as deep beams spanning between columns. Such wall beams may span as much as 20 to 30 ft (6 to 9 m).

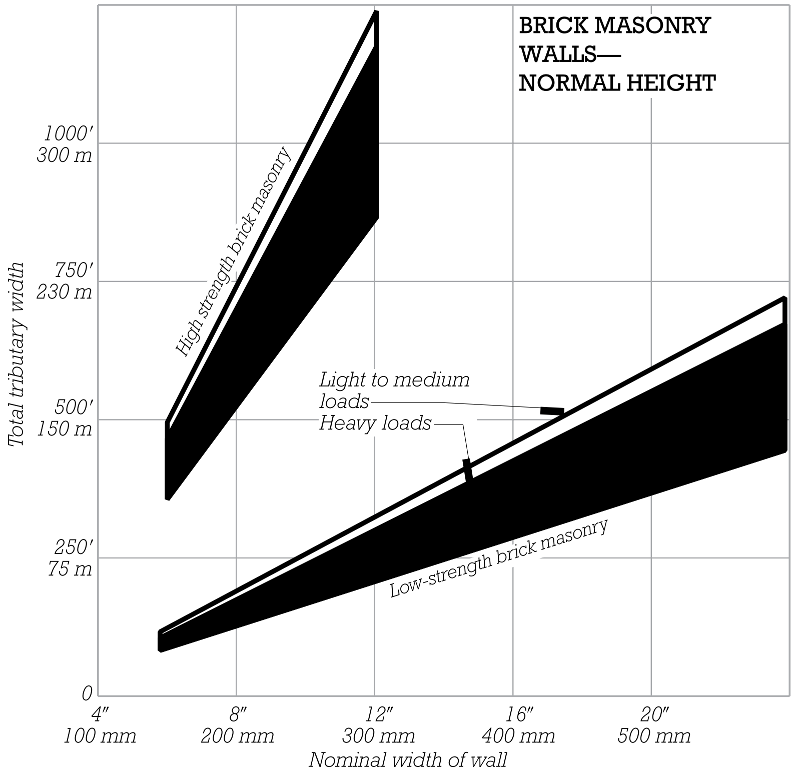


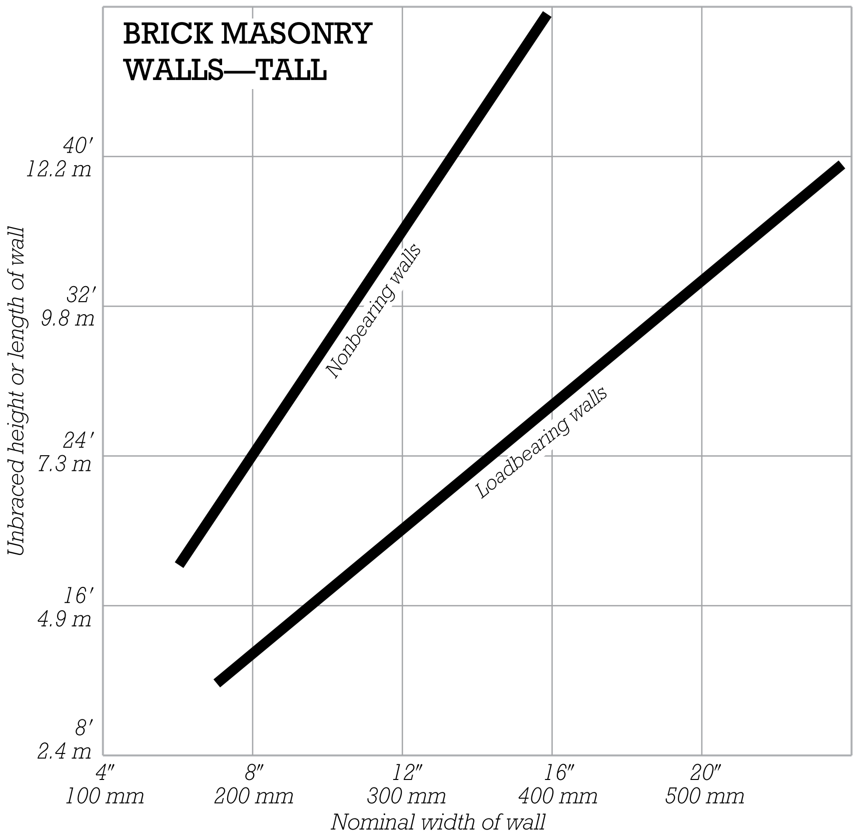
Bearing walls may act as deep beams to span across openings below, as shown in this schematic cross section.

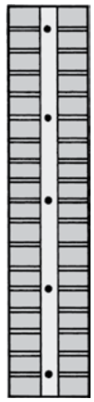
FIRE RESISTANCE AND BRICK MASONRY WALLS

Brick masonry construction may be used in both Combustible and Noncombustible Construction. The fire resistance of brick masonry construction varies with the type of brick unit. For preliminary design, assume that a 1-hour fire-resistance rating can be achieved with a 4-in. (100-mm)-thick wall, a 2-hour rating with a 6-in. (150-mm) wall, and a 3- to 4-hour rating with an 8-in. (200-mm) wall.

BRICK MASONRY WALLS





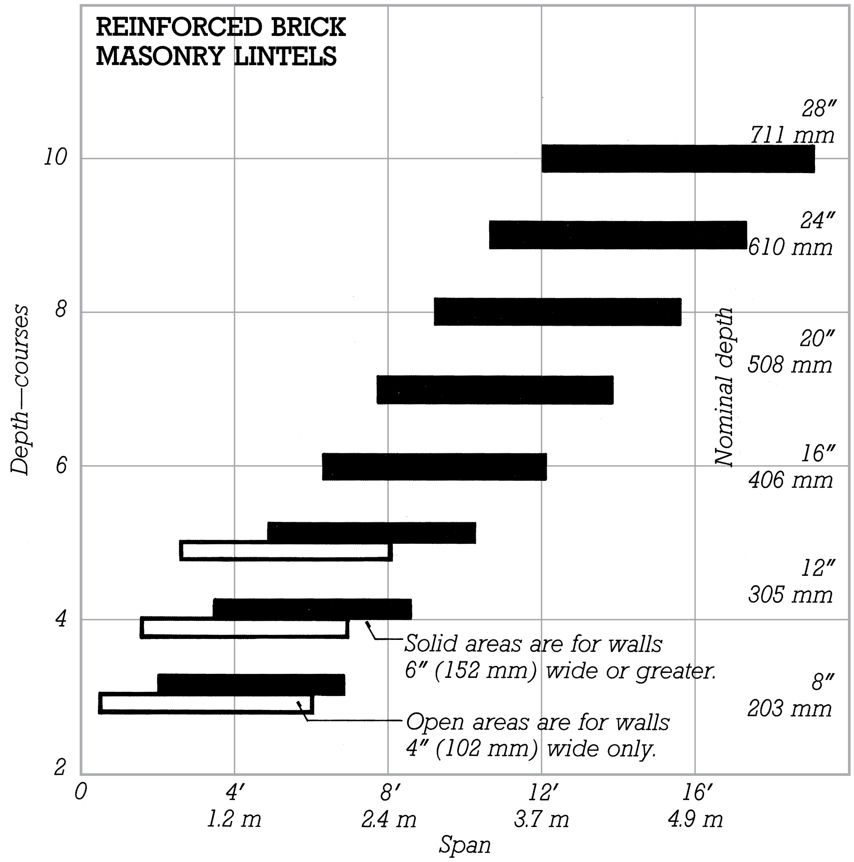


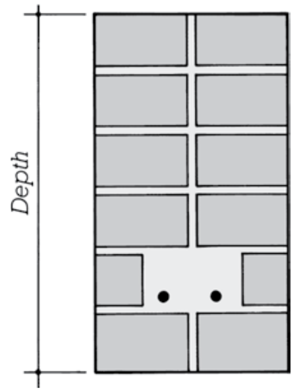
The top chart is for reinforced brick masonry walls up to 12 ft (3.7 m) tall between floors. For high-compressive-strength masonry, read from the upper set of curves. For low-strength masonry, read from the lower set. For light loads, read in the upper open areas of each curve; for medium to heavy loads, read in the lower solid areas. *Total tributary width* is one-half the span of one floor supported by the wall multiplied by the number of floors and the roof above.

■ For cavity walls, use only the net width of the structural wythe when reading the charts on this page.

■ Actual width of a wall is ⅜ in. (10 mm) less than the nominal size.

For walls greater than 12 ft (3.7 m) in height or unbraced length, read from both charts on this page, using the larger size indicated by either chart. Read along the *Loadbearing walls* curve for walls bearing gravity loads or wind loads. Read along the *Nonloadbearing walls* curve for interior nonloadbearing partitions. *Unbraced height of wall* is the vertical distance between floors. *Unbraced length of wall* is the horizontal distance between crosswalls or pilasters. See the facing page for more information on unbraced wall length.





The chart at the left is for steel-reinforced brick masonry lintels. For lintels carrying only wall loads, read toward the right in the indicated areas. For lintels carrying floor loads or other superimposed loads, read toward the left. For most applications, lintel depths of four to seven courses are sufficient.

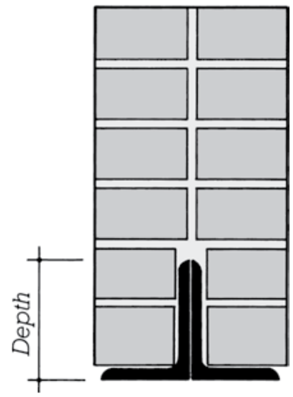
■ Depths for this chart are based on modular brick coursing where three courses = 8 in. (200 mm). For other coursing dimensions, read depths in inches from the right-hand scale, and round up to a whole course height.

■ Actual depth is the thickness of one mortar joint less than the nominal depth (approximately ½ in., or 13 mm).

STEEL ANGLE LINTELS

The following chart is for steel angle lintels carrying wall loads only. Heavier structural shapes, such as channels or wide-flange sections combined with plates, may be used where longer spans or greater load capacities are required.

Depth of Angle		Maximum Span	
3″	(76 mm)	5′	(1.5 m)
4″	(102 mm)	6′	(1.8 m)
5″	(127 mm)	7′	(2.1 m)
6″	(152 mm)	8′	(2.4 m)



STEEL ANGLE LINTEL

FIRE RESISTANCE AND BRICK MASONRY LINTELS

Brick masonry lintels may be used in both Combustible and Noncombustible Construction. Lintels not less than 8 in. (200 mm) in nominal dimension may be assumed to have a fire-resistance rating of 2 hours.

BRICK MASONRY ARCHES

MINOR BRICK ARCHES

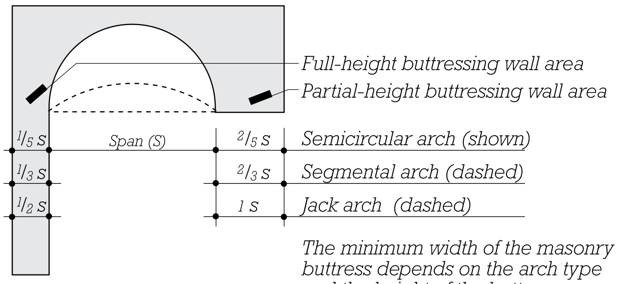
For spans of up to 6 to 8 ft (1.8 to 2.4 m), almost any shape of arch will work, particularly when the arch is embedded in a wall. Depths of minor brick arches typically range from 4 to 16 in. (100 to 400 mm). Thicknesses should be at least 4 to 8 in. (100 to 200 mm). Concentrated loads bearing directly on minor arches, especially jack arches, should be avoided.

Segmental arches are most efficient when the rise of the arch is between 0.08 and 0.15 times the span of the arch. See the following table for proportioning jack arches. Note that camber is not a structural requirement in a jack arch, but rather is used to avoid the appearance of sag. As an example of using the table, a jack arch 12 in. deep spanning 6 ft should have a ¾-in. camber (⅛″ × 6′) and 9-in. skewback (½″ × 6′ × 12″/4″) at each end.

JACK ARCH PROPORTIONS

Maximum Span without Lintel	Camber	Depth	Skewback
6′ (1800 mm)	⅛″ per foot of span (1:100)	8″ (200 mm) minimum	½″ per foot of span for every 4″ of arch depth (40 mm per meter of span for every 100 mm of arch depth)

The horizontal thrust produced by an arch must be resisted at its supports. This resistance can be provided by a tie rod acting in tension, the opposing thrust of an adjacent arch, or the buttressing action of an adjacent masonry wall area. When relying on abutting masonry, the minimum width of the masonry area depends on the type of arch and the vertical height of the abutting masonry. See the following diagram.



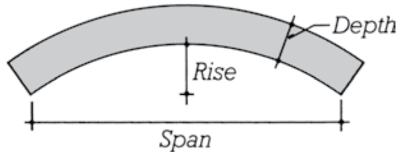
MASONRY BUTTRESS PROPORTIONS

MAJOR BRICK ARCHES

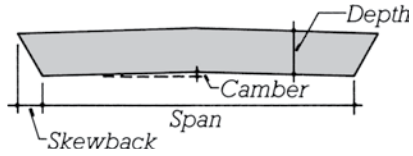
Major brick arches can span as far as approximately 250 ft (75 m). Parabolic shapes are recommended for long-span arches. Practical proportions for the rise of major arches range from approximately 0.2 to 0.6 times the span. For maximum efficiency, this proportion should not exceed 0.25.

FIRE RESISTANCE AND BRICK MASONRY ARCHES

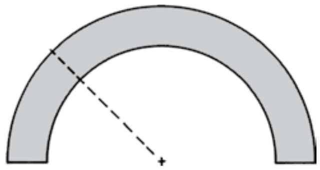
Brick masonry arches may be used in both Combustible and Noncombustible Construction. Arches not less than 8 in. (200 mm) in nominal dimension may be assumed to have a fire-resistance rating of 2 hours.



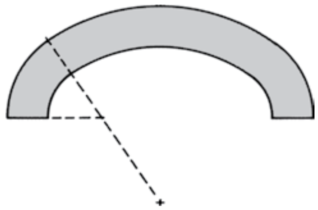
SEGMENTAL ARCH



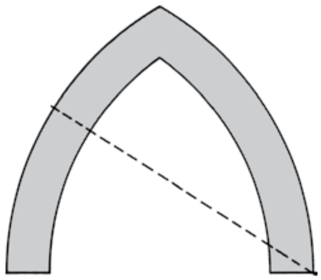
JACK ARCH



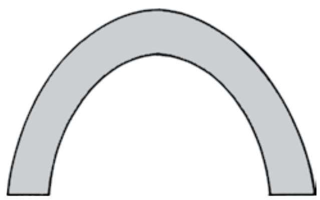
SEMICIRCULAR ARCH



MULTICENTERED ARCH



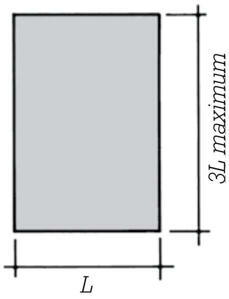
POINTED ARCH



PARABOLIC ARCH

MASONRY STRENGTH

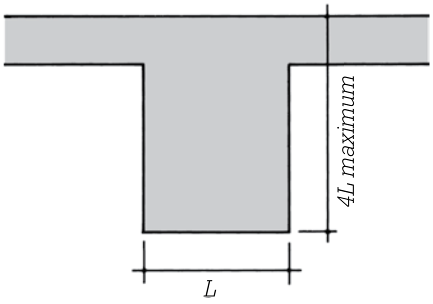
The strength and cost of concrete masonry increase as stronger concrete units, steel reinforcing, and mortar mixes are used in its construction. When reading the top chart on the facing page, begin by assuming low-strength masonry, and read from the lower set of bars. If the column sizes yielded by this result are impractically large, then consider using higher-strength masonry, reading from the upper set of bars or interpolating between the two sets.



RECTANGULAR COLUMNS

CONCRETE MASONRY COLUMN SIZES

For lightly loaded structures, the minimum size for reinforced concrete masonry columns is 8 in. (200 mm). For other conditions, use columns 12 in. (300 mm) square or larger. For rectangular columns, the wider side should be no more than three times the width of the narrower side. For pilasters (columns that are part of walls), the wider side should not exceed four times the width of the shorter side. For maximum economy, size concrete masonry columns in increments of 4 in. (100 mm).

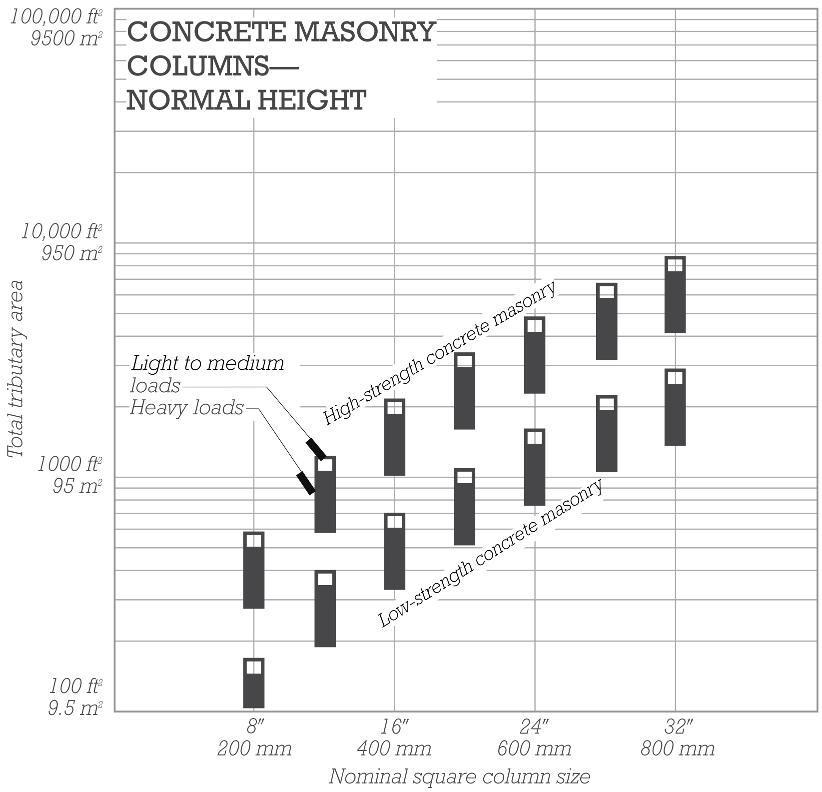


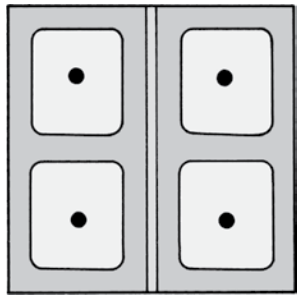
RECTANGULAR PILASTERS

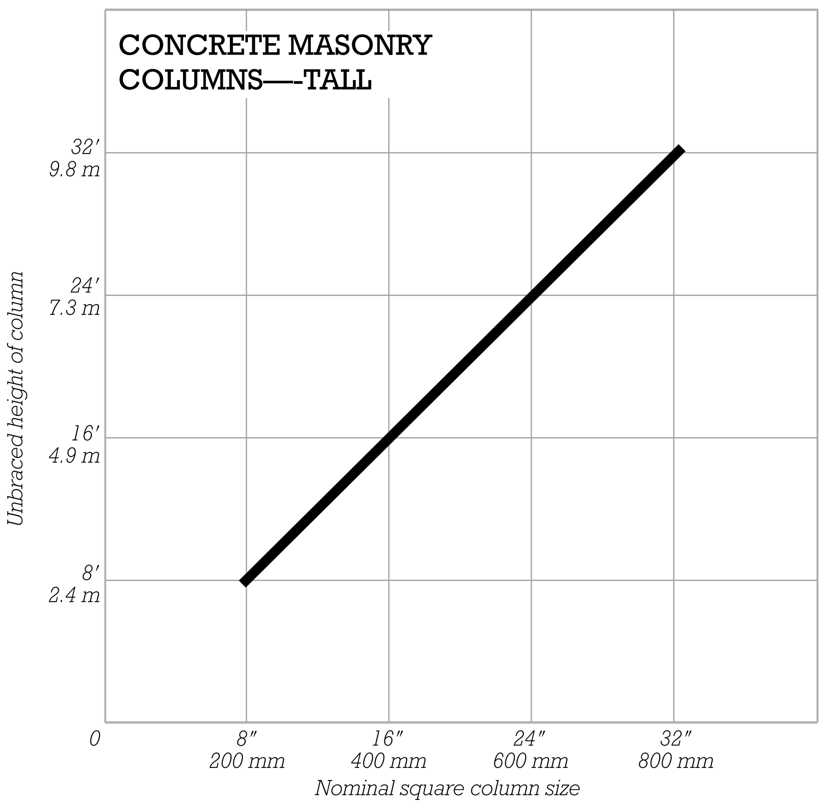
FIRE RESISTANCE AND CONCRETE MASONRY COLUMNS

Concrete masonry may be used in Combustible and Noncombustible Construction. The fire resistance of concrete masonry construction varies with the type of concrete units. For preliminary design, concrete columns with a least dimension of 8 in. (200 mm) may be assumed to have a fire-resistance rating of 1 hour, and those with least dimensions of 10 in. (250 mm), 12 in. (300 mm), and 14 in. (350 mm) to have fire-resistance ratings of 2, 3, and 4 hours, respectively.

CONCRETE MASONRY COLUMNS







The top chart is for concrete masonry columns up to 12 ft (3.7 m) tall between floors. For high-compressive-strength masonry, read from the upper set of bars. For low-strength masonry, read from the lower set. For light to medium loads, read in the upper open areas of each bar; for heavy loads, read in the lower solid areas. *Total tributary area* is the summed area of the roof and all floors supported by the column.

■ For rectangular columns, select a column of area equal to the square size indicated.

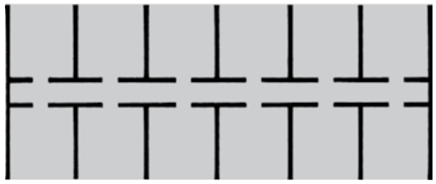
■ Actual column size is ⅜ in. (10 mm) less than nominal size.

For columns taller than 12 ft (3.7 m), read from both charts on this page, using the larger size indicated by either chart. *Unbraced height of column* is the vertical distance between floors or other supports that brace the column laterally against buckling.

■ For rectangular columns, read *Nominal square column size*, using the lesser dimension of the column.

MASONRY STRENGTH

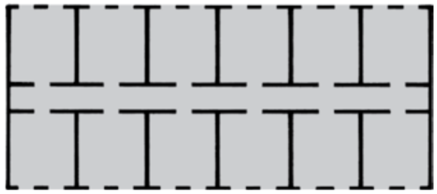
The strength and cost of concrete masonry increase as stronger concrete units, steel reinforcing, and mortar mixes are used in its construction. When reading the top chart on the facing page, begin by assuming low-strength masonry, and read from the lower set of bars. If the wall sizes yielded by this result are impractically large, then consider using higher-strength masonry, reading from the upper set of bars, or interpolate between the two sets.



LOW-RISE BEARING WALL CONFIGURATION ***(shown in plan)***

CAVITY WALLS

For cavity walls, use only the nominal width of the structural wythe when reading the charts on the facing page.

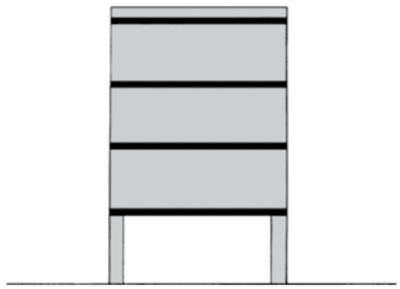


HIGH-RISE BEARING WALL CONFIGURATION ***(shown in plan)***

MINIMUM WIDTHS OF WALL

For most construction, 8 in. (200 mm) is the minimum practical width for reinforced concrete masonry walls. Although walls 6 in. (150 mm) wide are feasible, they are difficult to construct and only suitable for supporting light loads.

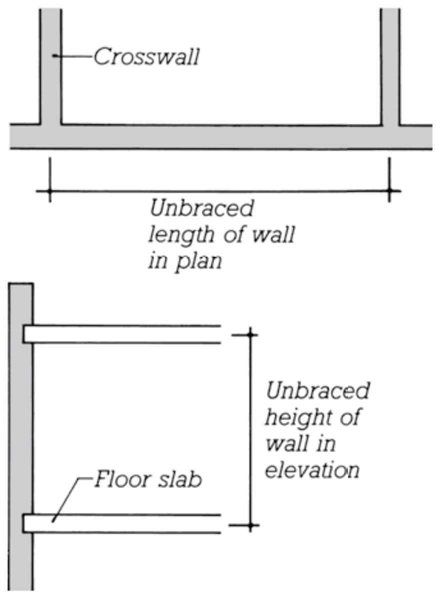
The minimum width for unreinforced masonry walls is 8 in. (200 mm) for the support of light loads, or 12 in. (300 mm) for heavier loads. The use of unreinforced masonry construction in modern buildings is rare due to this system's lack of resistance to seismic forces. For more information on the design of loadbearing masonry structures, see Designing with Masonry Bearing Walls, on page 84.



Bearing walls may act as deep beams to span across openings below, as shown in this schematic cross section.

MAXIMUM UNBRACED LENGTH OF WALL

Use the bottom chart on the facing page to determine the maximum permissible unbraced length of wall in plan, in addition to its maximum permissible height. Masonry walls should be braced by crosswalls spaced at distances not exceeding those indicated on the chart. If the proposed crosswall spacing in your design is too great, either thicken the wall or add pilasters at intermediate spacing (see pages 88–89 for sizing of pilasters).

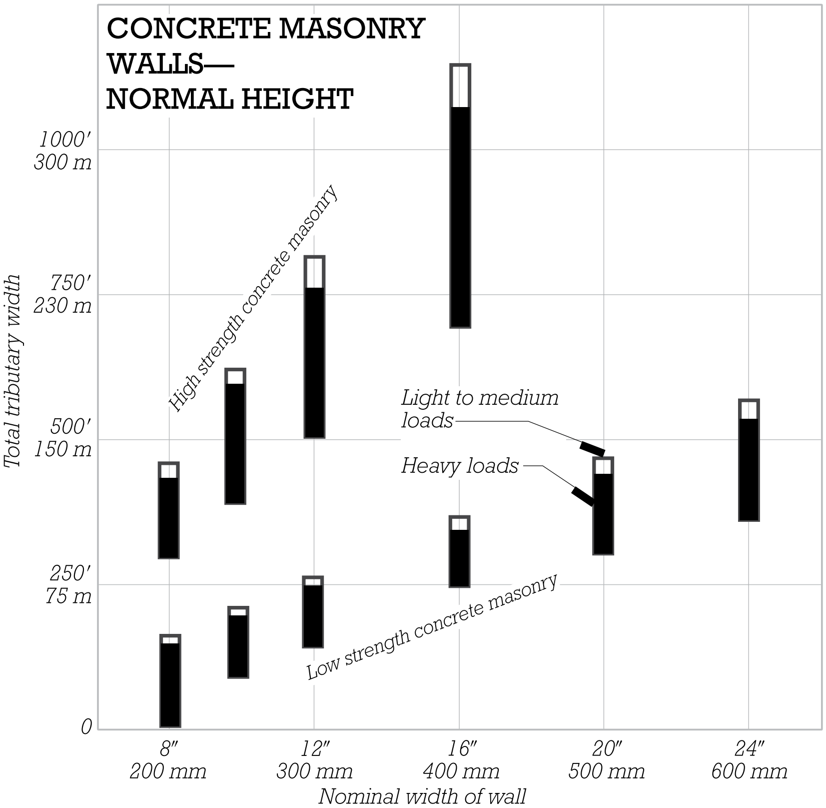


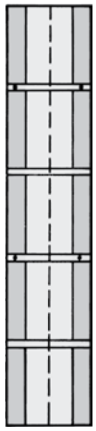
UNBRACED HEIGHT OR LENGTH OF MASONRY WALLS

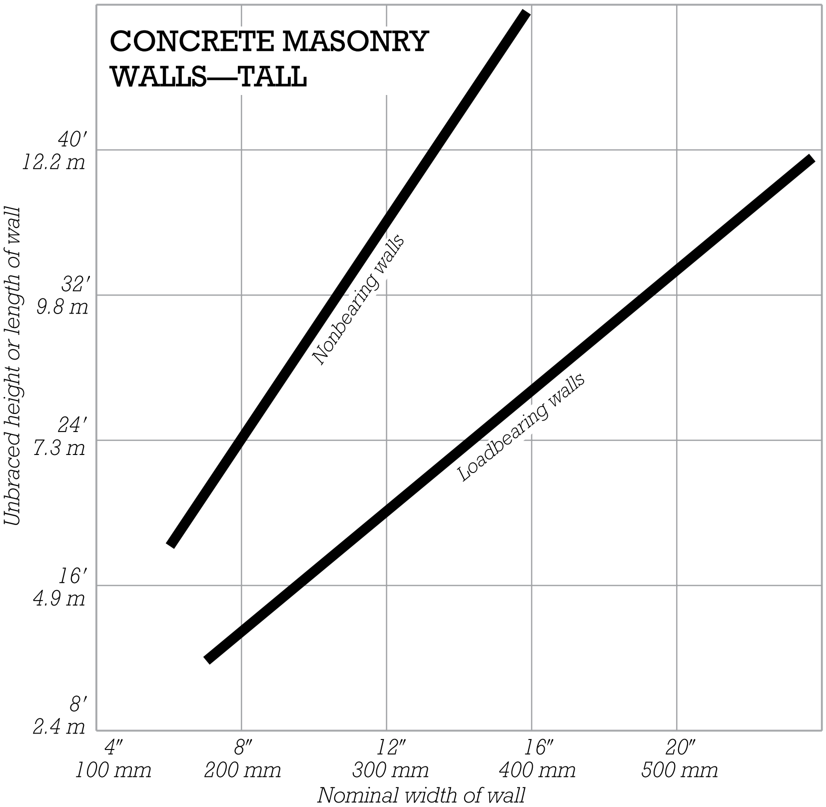
FIRE RESISTANCE AND CONCRETE MASONRY WALLS

Concrete masonry construction may be used in both Combustible and Noncombustible Construction. The fire resistance of concrete masonry construction varies with the type of masonry unit. For preliminary design, assume that a 1-hour fire-resistance rating can be achieved with a 6-in. (150-mm)-thick wall, a 2-hour rating with an 8-in. (200-mm) wall, and a 3- to 4-hour rating with a 10-in. (250-mm) wall.

CONCRETE MASONRY WALLS







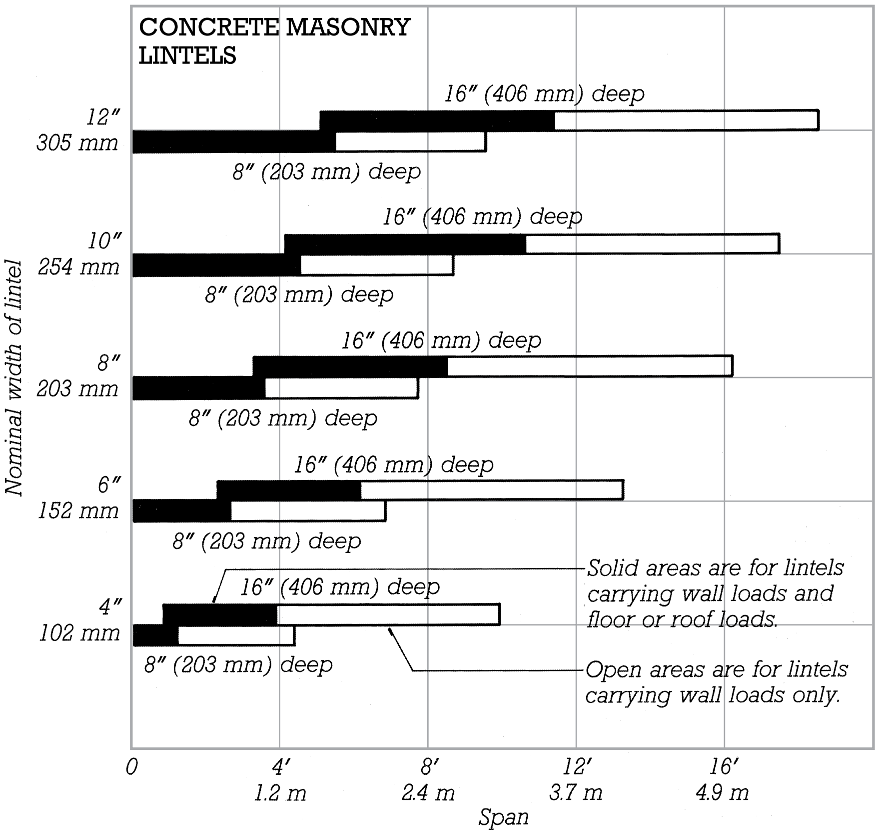
The top chart is for reinforced concrete masonry walls up to 12 ft (3.7 m) tall between floors. For high-compressive-strength masonry, read from the upper set of bars. For low-strength masonry, read from the lower set. For light loads, read in the upper open areas of each bar; for medium to heavy loads, read in the lower solid areas. *Total tributary width* is one-half the span of one floor supported by the wall multiplied by the number of floors and the roof above.

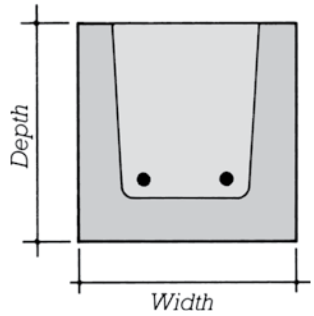
■ For unreinforced masonry walls, increase the indicated width of the wall thickness by 25%.

■ Actual width of the wall is ⅜ in. (10 mm) less than nominal size.

For walls greater than 12 ft (3.7 m) in height or unbraced length, read from both charts on this page, using the larger size indicated by either chart. Read along the solid line for the appropriate wall type. *Unbraced height of wall* is the vertical distance between floors. *Unbraced length of wall* is the horizontal distance between crosswalls or pilasters. See the facing page for more information on unbraced wall length.

CONCRETE MASONRY LINTELS





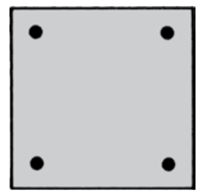
The chart at the left is for steel-reinforced concrete masonry lintels. Open areas are for lintels carrying wall loads only. Solid areas are for lintels carrying wall loads and floor or roof loads. For light loads, read toward the right in the indicated areas. For heavy loads, read toward the left.

■ Actual sizes are equal to nominal size less ⅜ in. (10 mm).

PRECAST CONCRETE AND STRUCTURAL STEEL LINTELS

Precast concrete lintels that are 8 in. (200 mm) deep can span up to approximately 8 ft (2.4 m). Lintels 16 in. (400 mm) deep can span up to approximately 16 ft (4.9 m).

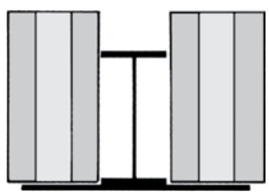
Lintels made of combinations of steel angles can span up to approximately 8 ft (2.4 m). Greater spans are possible with heavier structural steel shapes, such as channels or wide-flange sections combined with plates.



PRECAST CONCRETE LINTELS

FIRE RESISTANCE AND CONCRETE MASONRY LINTELS

Concrete masonry lintels may be used in both Combustible and Noncombustible Construction. The fire resistance of concrete masonry construction varies with the composition and design of the masonry units themselves. For preliminary design, concrete masonry lintels not less than 8 in. (200 mm) in nominal dimension may be assumed to have a fire-resistance rating of 1 to 2 hours.



STRUCTURAL STEEL LINTELS

STEEL STRUCTURAL SYSTEMS

Steel elements are of two basic types: *Lightweight steel framing* members are cold-formed from thin steel sheets or rods. Such elements include roof and floor decking and a variety of light framing members such as channels, studs, and joists. Heavier *structural steel* members are formed into their final shapes by hot-rolling. This method produces such common elements as wide-flange sections, angles, channels, bars, and plates.

LIGHTWEIGHT STEEL FRAMING

Lightweight steel framing (also called light gauge steel framing) finds applications in low-rise structures where the light weight and ease of assembly of these elements are advantages. Many of the details of this system and the sizes of the structural elements are similar to those used in Wood Light Frame Construction, a system that lightweight steel framing often competes with in the marketplace. However, the noncombustibility of steel allows this system to be used in building types where wood construction is not permitted. The small size of the individual structural elements and the reliance on on-site fabrication also make this system a good choice where buildings of irregular form are desired. See pages 386–388 for more information about the use of lightweight steel framing in buildings of noncombustible construction types.

STRUCTURAL STEEL FRAMING

Conventional hot-rolled structural steel is a versatile material that has applications ranging from single-story structures to the world's tallest buildings. The extent of prefabrication normally used with structural steel results in a system that is precise and rapidly erected.

Structural steel elements are normally configured as a post and beam frame. The slab system most commonly used with structural steel framing is a sitecast concrete slab poured over corrugated steel decking. Other sitecast or precast concrete systems are also used. Steel frames can support all varieties of cladding systems, with curtain walls of steel, aluminum, glass, masonry, and stone being the most common.

Due to steel's rapid loss of strength at elevated temperatures, it must often be concealed behind fire-resistive materials or assemblies. See pages 386–388 for more information on the requirements for fire protection of structural steel.

SIZE, WEIGHT, AND SPACING OF LIGHTWEIGHT STEEL STUDS

The charts on the facing page list the most commonly available sizes of lightweight steel studs. Other sizes may be available from some manufacturers. Studs typically vary in width from 1 ⅜ to 2½ in. (35 to 64 mm). For preliminary purposes, a width of 2 in. (50 mm) may be assumed.

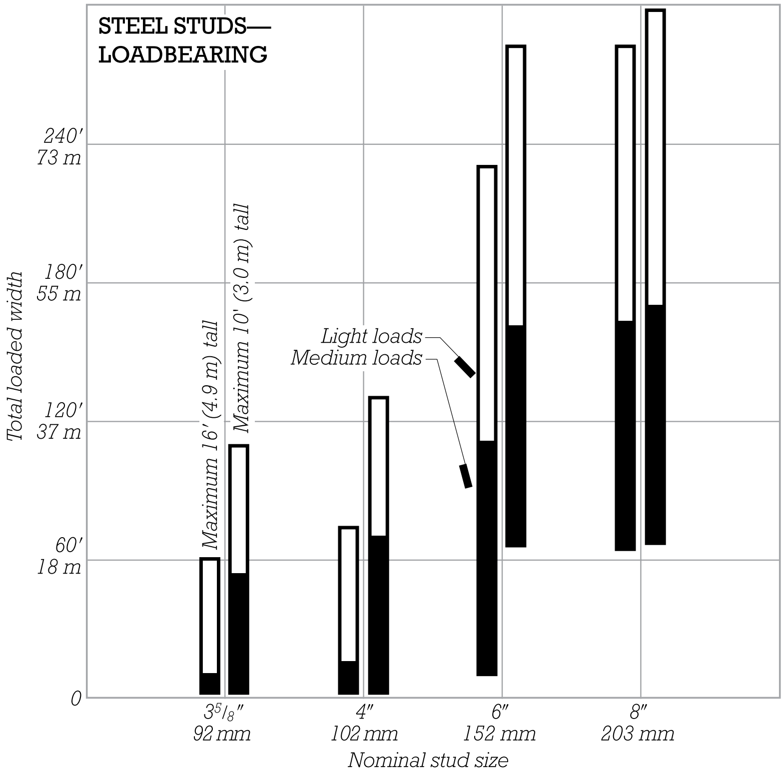
The load-carrying capacity of lightweight steel studs varies with the strength and thickness of the steel sheet from which the studs are made. In the charts on the facing page, the highest values indicated in each stud size represent studs manufactured from thicker, higher-strength metal. Lower values represent studs manufactured from thinner, lower-strength material.

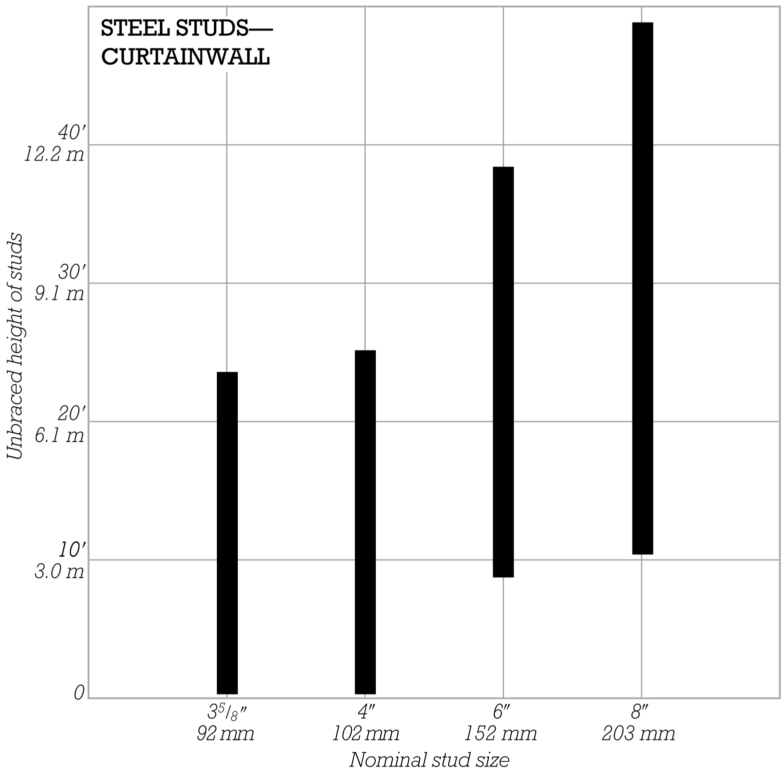
The capacity of steel stud systems also depends on the spacing of the studs. Studs should always be spaced on a 4-ft (1200-mm) module to coordinate with standard wall panel widths. The most common spacings are 12, 16, and 24 in. (300, 400, and 600 mm) on center. In the charts on the facing page, the highest values shown for each stud size represent framing systems with studs spaced at 12 in. (300 mm). Lower values represent systems with studs spaced at 16 or 24 in. (400 or 600 mm).

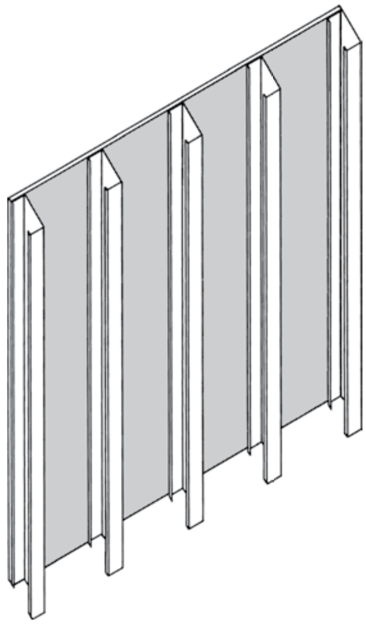
FIRE RESISTANCE AND STEEL STUD FRAMING

Lightweight steel stud construction may be used in both Combustible and Noncombustible Construction. To achieve a 1-hour fire-resistance rating, framing may be covered with rated gypsum board or plaster materials in thicknesses ranging from ½ to 1 in. (12 to 25 mm). Fire-resistance ratings of up to 4 hours can be achieved with finishes ranging in thickness from 2 to 3 in. (50 to 75 mm). Even where no fire-resistance rating is required, steel stud framing typically must be covered with some form of wallboard or panel material to stabilize its relatively slender members against buckling.

LIGHTWEIGHT STEEL WALL STUDS







The top chart is for loadbearing lightweight steel stud walls. For walls up to 10 ft (3.0 m) high, read from the taller right-hand bars. For walls up to 16 ft (4.9 m) high, read from the left-hand bars. For light loads, read in the open areas of each bar. For medium loads, read in the solid areas. *Total loaded width* is the tributary width of one floor (one-half of its span) multiplied by the number of floors and roof above the wall.

■ Actual stud depth is equal to the nominal size.

The lower chart is for curtain wall studs—studs resisting wind, but not gravity loads. For light wind loads and for cladding systems such as glass or metal that are relatively tolerant of deflection, read toward the top in the indicated areas. For heavy wind loads and for claddings of stone, clay masonry, or other materials requiring stiffer support, read toward the bottom. *Unbraced height of studs* is the vertical distance between floors or other supports.

■ Stud height may be increased with the addition of intermediate bracing perpendicular to the wall plane.

SIZE, WEIGHT, AND SPACING OF LIGHTWEIGHT FLOOR JOISTS

The chart on the facing page lists the most commonly available sizes of lightweight steel floor joists. Other sizes may be available from some manufacturers. Joists typically vary in width from 1 ⅝ to 2½ in. (35 to 64 mm). For preliminary purposes, a width of 2 in. (50 mm) may be assumed.

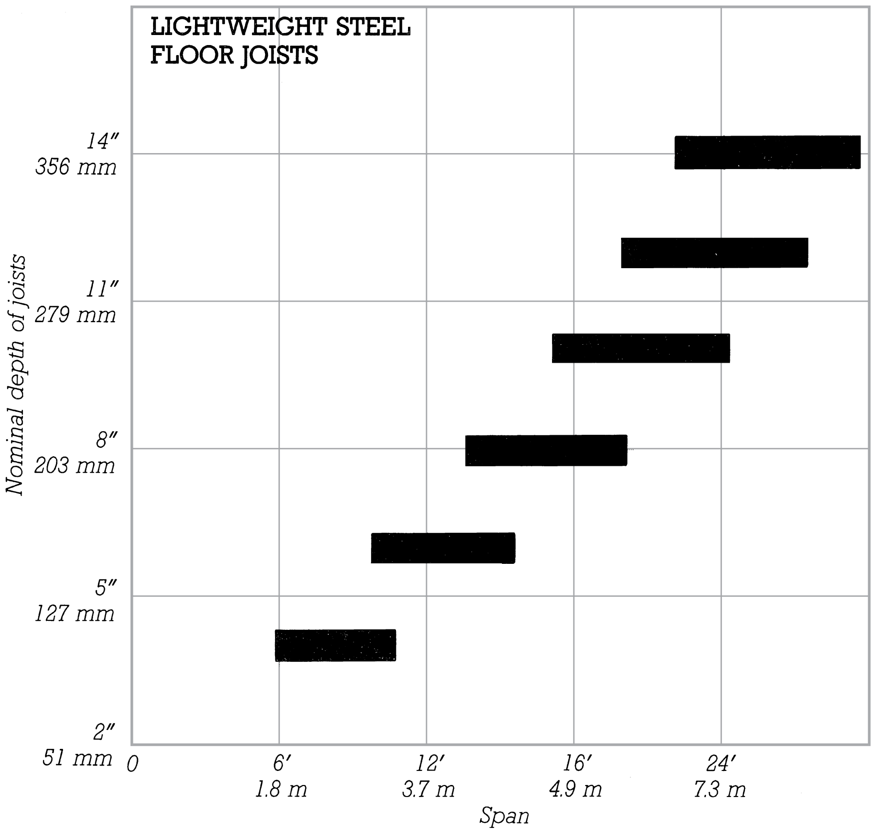
The load-carrying capacity of lightweight steel joists varies with the strength and thickness of the steel sheet from which the joists are made. In the chart on the facing page, the longest spans indicated in each joist size represent joists manufactured from thicker, higher-strength sheet metal. Shorter spans represent joists manufactured from thinner, lower-strength material.

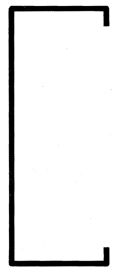
The capacity of steel joist framing also depends on the spacing of the joists. Joists should always be spaced on a 4-ft (1200-mm) module to coordinate with standard floor panel widths. The most common spacings are 16 and 24 in. (400 and 600 mm) on center. In the chart on the facing page, the longest spans shown for each joist size represent framing with joists more closely spaced, and shorter spans represent systems with joists at greater spacings.

FIRE RESISTANCE AND LIGHTWEIGHT STEEL

Lightweight steel floor joists may be used in both Combustible and Noncombustible Construction. Fire-resistance ratings of 1 to 2 hours may be achieved with ceilings of gypsum board or plaster in thicknesses ranging from 1 to 2 in. (25 to 50 mm).

LIGHTWEIGHT STEEL FLOOR JOISTS





This chart is for lightweight steel floor joists. For light loads, close joist spacings, or joists made from stronger, thicker steel sheet metal, read toward the right in the indicated areas. For heavy loads, wide spacings, or studs made of less strong, thinner sheet metal, read toward the left.

■ Actual size is equal to nominal size less from 0 to ¾ in. (19 mm), depending on the manufacturer.

COLUMN LAYOUT

Columns at the perimeter of a building should be oriented with their flanges facing outward, wherever possible, to facilitate the attachment of cladding to the building's structural frame. Elsewhere, columns should be oriented with their webs parallel to the axis on which the building is most vulnerable to lateral forces, so that the columns may make the greatest contribution to resisting these forces. For example, in buildings with rectangular footprints, the weaker axis is most frequently parallel to the shorter sides of the structure, and orienting column webs parallel to this shorter axis would be preferred.

FINISH DIMENSIONS OF STEEL COLUMNS

In most cases, structural steel columns are not exposed in the completed construction, and their overall finish dimensions must be increased from those shown in the charts on the facing page to account for the application of fireproofing and finishes. The added thickness depends on the materials involved, the degree of fire resistance required, and the weight of the steel section itself (heavier sections require less added fire protection than lighter ones). For common conditions, an allowance of 1 to 4 in. (25 to 100 mm) per side of column should be sufficient for preliminary sizing. When applying these allowances to the actual column sizes, remember to double them to account for materials applied to opposite sides of the column, that is, 2 to 8 in. (50 to 200 mm) total.

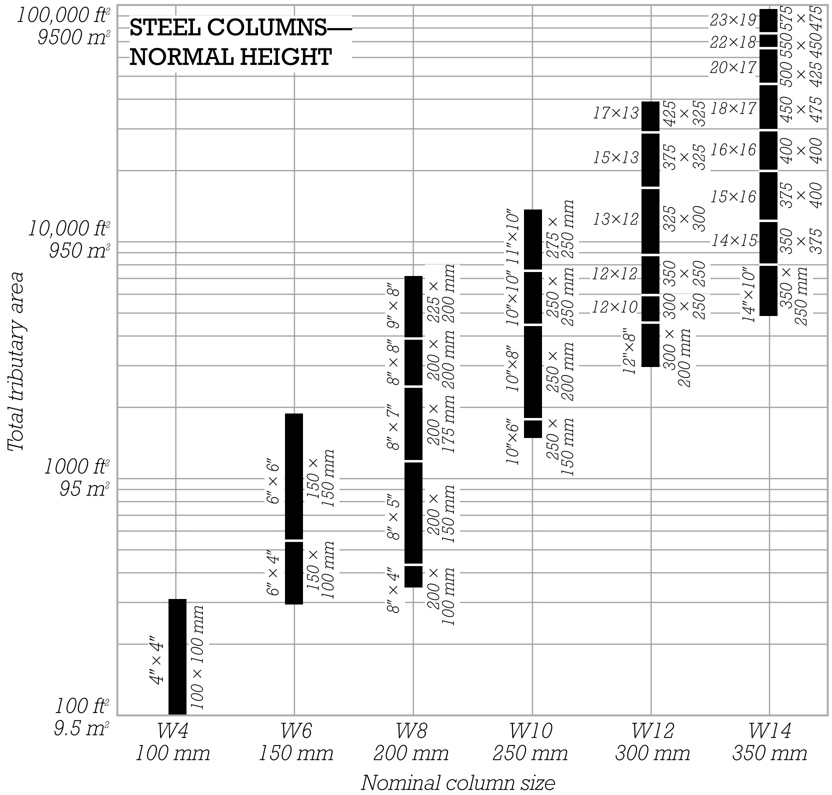
As a more costly alternative, in cases where fire protection is required but there is a desire for steel to remain exposed, thin paintlike intumescent coatings may be applied to the steel. These coatings add negligibly to the size of the column. Under fire conditions, they expand to form an insulating layer that protects the steel from the heat of the fire.

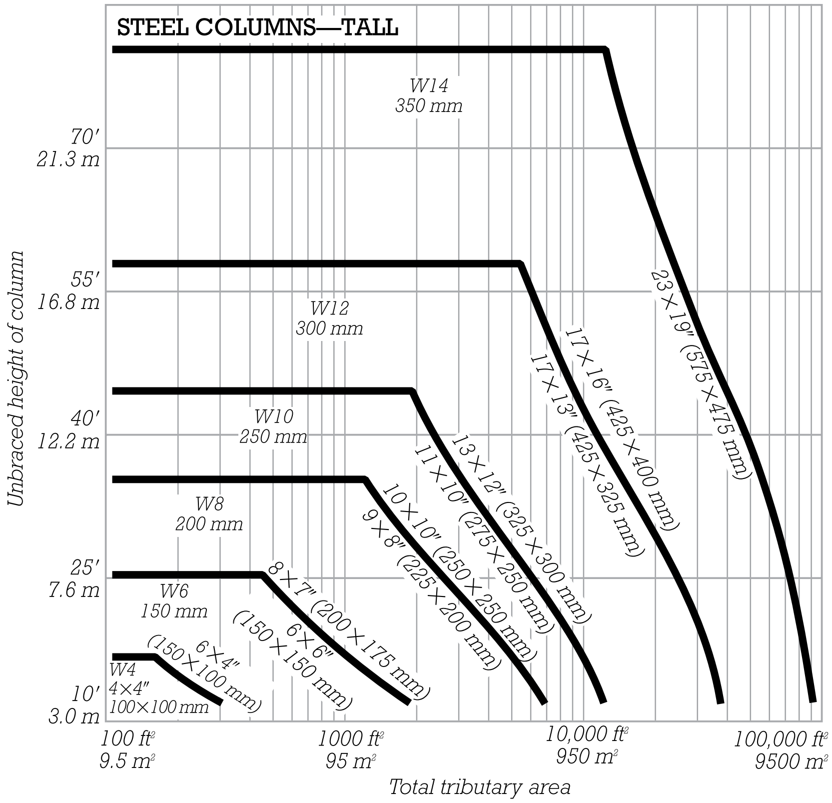
Depending on how individual sections of a column are connected, an additional allowance of 1 to 2 in. (25 to 50 mm) per side may be required, added to the deeper dimension of the column, to account for splice plates and fasteners where column joints occur. Where required, these connections typically are located several feet above the floor level.

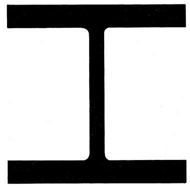
FIRE RESISTANCE AND STRUCTURAL STEEL COLUMNS

Exposed structural steel columns may be used in both Unprotected Noncombustible and Unprotected Combustible Construction. For Protected Construction Types, fire-resistance ratings of up to 4 hours are easily achieved with any number of fireproofing materials, in thicknesses of as little as 1 to 4 in. (25 to 100 mm). As an alternative, intumescent coatings, as described in the preceding section, Finish Dimensions of Steel Columns, can provide up to 3 to 4 hours of fire resistance, depending on the size of the steel member.

STRUCTURAL STEEL COLUMNS







The top chart is for steel wide-flange section columns up to 12 ft (3.7 m) tall between floors. *Total tributary area* is the summed area of the roof and all floors supported by the column.

■ For medium loads, read directly from the chart. For light loads, reduce the total tributary area supported by the column by 10% before reading the chart; for heavy loads, increase the area supported by 15%.

■ Actual column sizes are shown to the sides of the bars. Not all available sizes are shown. Consult a steel handbook for additional options.

■ For columns located at the perimeter of a building or forming part of a rigid frame system, select one nominal size larger than the least nominal size indicated by this chart.

■ W14 sections are the largest standard rolled sizes commonly available for use as columns. Larger built-up sections capable of carrying greater loads may be shop-fabricated.

For columns taller than 12 ft (3.7 m), read from both charts on this page, using the larger column size indicated by either one. *Unbraced height of column* is the vertical distance between floors or other supports that brace the column laterally against buckling.

■ Actual column sizes are shown alongside the nominal shape curves. Intermediate sizes between those shown may be interpolated.

■ Minimum column size will be larger for heavily loaded columns or columns that are part of rigid frame systems.

STRUCTURAL HOLLOW STEEL SECTIONS

Standard shapes for structural hollow steel sections (commonly abbreviated as HSS on structural drawings and in technical literature) include square tubes, rectangular tubes, and round pipes. Compared to wide-flange sections of the same weight, tubes and pipes are more resistant to buckling forces, making them good choices for columns and compressive struts in all types of steel systems. They are employed as columns in long-span steel structures for their greater efficiency, and, because they are available in lighter weights than other standard shapes, they are frequently used in one- or two-story steel structures as well. HSS members are popular choices for use in the fabrication of steel trusses and space frames, and their high torsional resistance makes them excellent choices for single post supports such as for signs or platforms.

The simple profiles and clean appearance of hollow steel sections and pipes also make them popular for use where the steel may remain visible in the finished structure, or for structures exposed to the weather where absence of moisture- and dirt-trapping profiles and ease of maintenance are desirable characteristics. Tubes and pipes are generally available in whole-inch (25-mm) sizes up to 6 or 8 in. (152 or 203 mm) and in even-inch (51-mm) increments up to 12 to 16 in. (305 to 406 mm).

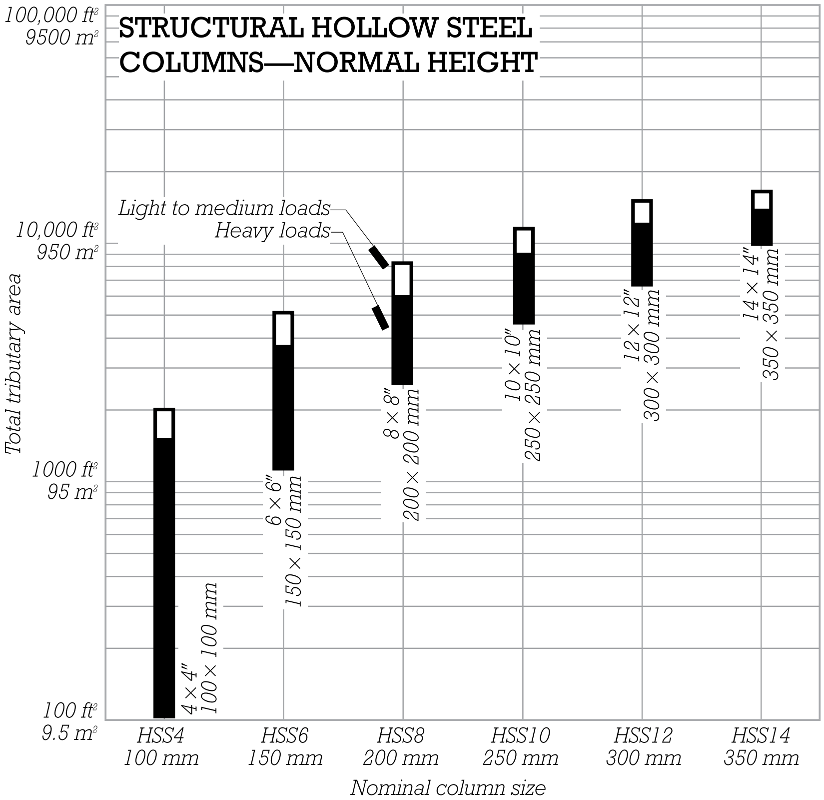
FINISH DIMENSIONS OF HOLLOW STEEL SECTION COLUMNS

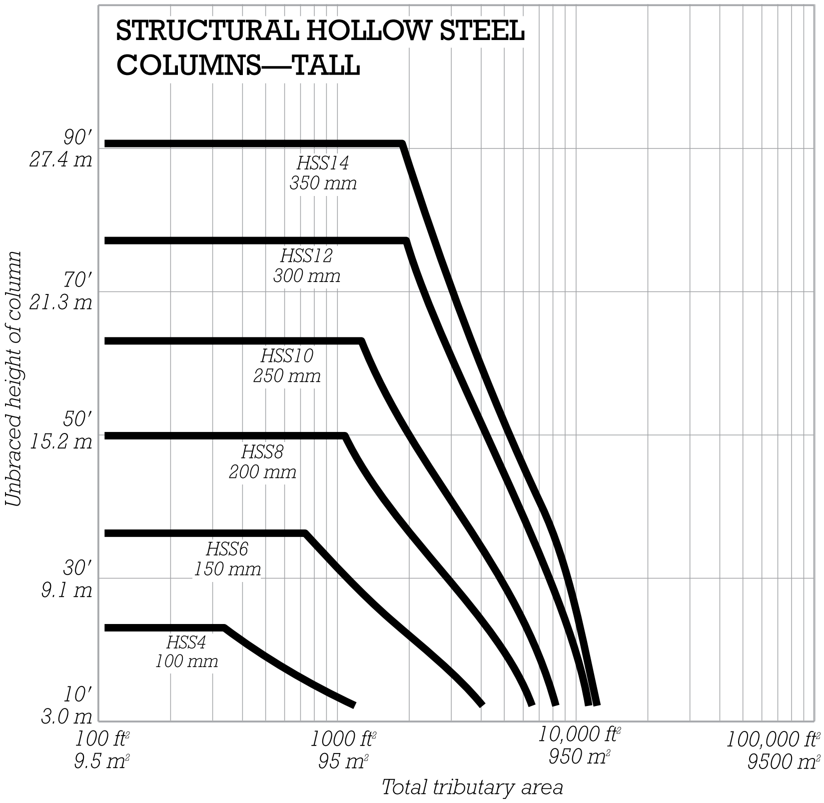
Where finishes are applied to hollow steel section columns, the added thickness depends on the materials involved, the degree of fire resistance required, and the weight of the steel section itself (heavier sections require less added fire protection than lighter ones). For preliminary sizing, an allowance of 1 to 4 in. (25 to 100 mm) per side of column should be sufficient (a total of 2 to 8 in. or 50 to 200 mm, accounting for both sides of the column). In cases where fire protection is required but there is a desire for steel to remain exposed, more costly paintlike intumescent coatings may be applied to the steel. Under fire conditions, these normally thin coatings expand to form an insulating layer that protects the steel from the heat of the fire.

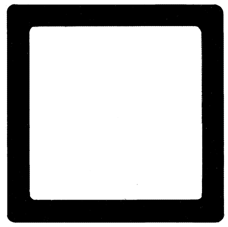
FIRE RESISTANCE AND HOLLOW STEEL SECTION COLUMNS

Exposed hollow steel section columns may be used in both Unprotected Noncombustible and Unprotected Combustible Construction. For Protected Construction Types, fire-resistance ratings of up to 3 hours for very light sections and 4 hours for heavier ones are achievable with any number of conventional fireproofing materials, applied in thicknesses of 2 to 4 in. (100 to 200 mm) per side. Fire-resistance ratings of up to 3 to 4 hours can also be achieved with intumescent coatings, as described in the preceding section Finish Dimensions of Steel Columns, or with specially designed hollow section columns filled with concrete.

STRUCTURAL HOLLOW STEEL COLUMNS







The top chart is for hollow steel section columns up to 12 ft (3.7 m) tall between floors. Read in the top open areas for light and medium loads. Read in the lower solid areas for heavy loads. *Total tributary area* is the summed area of the roof and all floors supported by the column.

■ Actual column size is equal to nominal size.

■ For columns located at the perimeter of a building, or ones that are part of a rigid frame system, select one nominal size larger than the size indicated by this chart.

For columns taller than 12 ft (3.7 m), read from both charts on this page, using the larger column size indicated by either one. *Unbraced height of column* is the vertical distance between floors or other supports that brace the column laterally against buckling.

■ Minimum column size will be larger for heavily loaded columns or columns that are part of rigid frame systems.

STEEL FLOOR DECKING

Corrugated steel floor decking with a sitecast concrete topping is the slab system most commonly used over structural steel framing. Typical span ranges for steel floor decking used with structural steel framing are 6 to 15 ft (1.8 to 4.6 m). Longer spans or shallower depths than those indicated on the chart on the facing page may be possible, although increased construction costs may result from the need for additional temporary shoring of the decking during erection.

CELLULAR FLOOR DECKING

The use of cellular decking to provide concealed spaces within the floor slab for the running of electrical and communications wiring may influence the framing plan for the building. Layout requirements for such wiring systems may determine the direction in which the decking cells will run in various areas of the building plan. The orientation of the beams or joists carrying the decking will, in turn, run perpendicular to the cells in the decking. See page 213 for additional information on the planning of such systems.

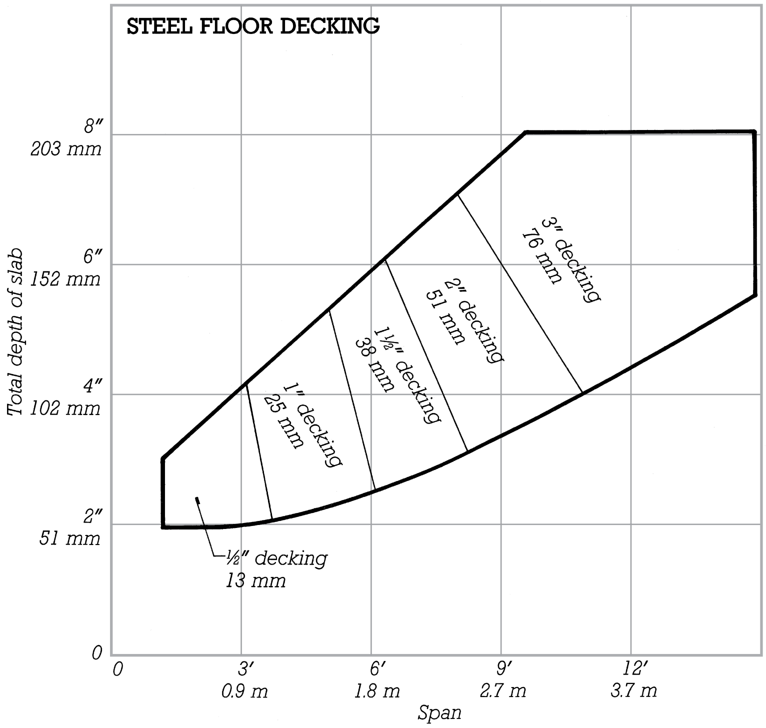
STEEL ROOF DECKING

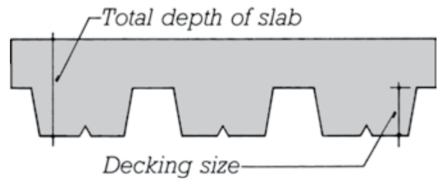
Steel roof decking may have a sitecast concrete or gypsum topping, or may be covered directly with a variety of board or roofing products. A common and economical configuration for roof decking is 1½-in. (38-mm) metal decking spanning up to 8 ft (2.4 m). Many proprietary metal roof decking systems, with a wide variety of performance characteristics, are available. Consult manufacturers for more information.

FIRE RESISTANCE AND STEEL DECKING

Steel roof and floor decking may be used in both Combustible and Noncombustible Construction. The fire resistance of roof or floor decking with a concrete topping varies with the configuration of the decking and the thickness of the topping. Although resistance ratings as high as 3 hours may be possible, for preliminary design, assume that decking must be protected with applied fireproofing or an appropriately fire-resistive ceiling to achieve ratings of more than 1 hour.

STEEL FLOOR AND ROOF DECKING



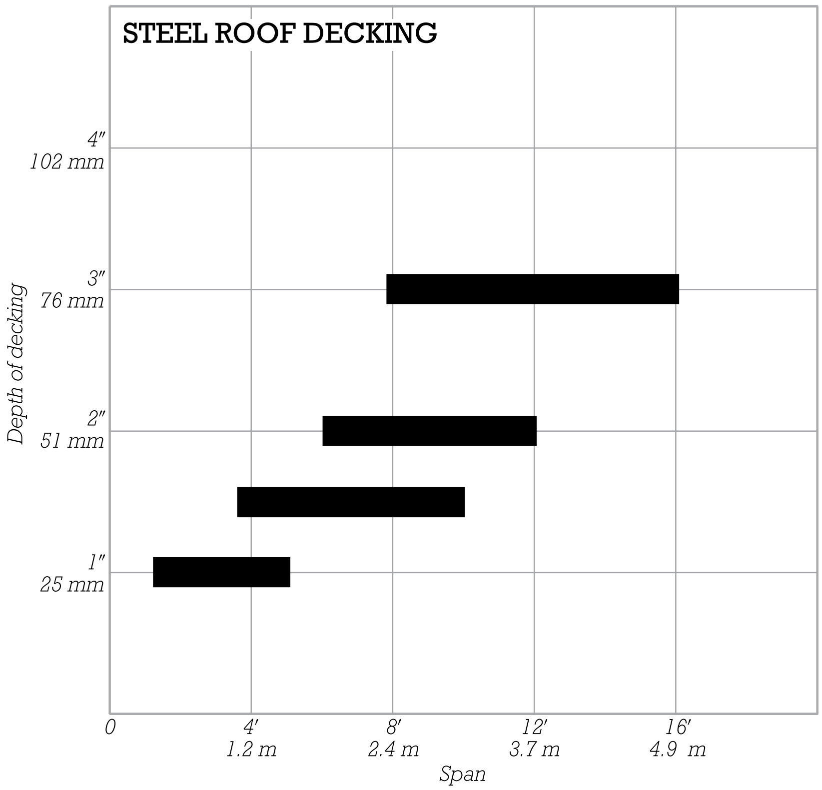


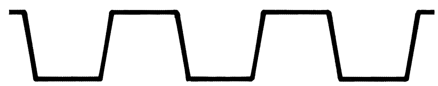
The top chart is for corrugated or cellular steel floor decking with concrete slab topping. For light loads, read toward the bottom in the indicated areas. For heavy loads, read toward the top.

■ *Total depth of slab* is the combined depth of the decking and the concrete topping. Approximate sizes for the steel decking alone are shown within the chart.

■ For cellular decking, read toward the bottom in the indicated areas.

■ Deeper deck sections with span capabilities exceeding 30 ft (9 m) are available from some manufacturers.





The bottom chart is for corrugated steel roof decking. For light loads, read toward the right in the indicated areas. For heavy loads, read toward the left.

■ Deeper section decking with spans exceeding 30 ft (9 m) is available from some manufacturers.

Structural steel is a versatile building material. While it can be used in a great variety of ways, consider the following guidelines for what is most economical in common practice.

FLOOR AND ROOF FRAMING

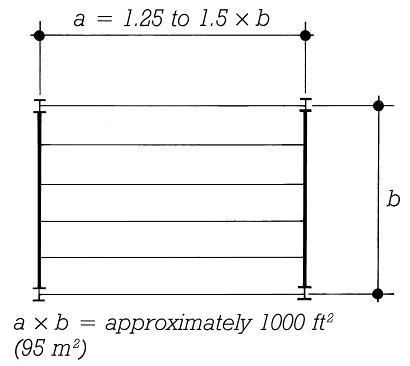
The most economical span range for conventional steel floor and roof framing is 25 to 40 ft (8 to 12 m). Individual column bays should be approximately 1000 sq ft (95 m^2) in area and rectangular in shape, with the long side 1.25 to 1.5 times as long as the shorter side. Above spans of approximately 40 ft (12 m), consider open-web steel joists for their lighter weight and greater economy (see page 106).

The spacing between individual beams depends on the applied loads and the decking system. Spacings from 6 to 15 ft (1.8 to 4.6 m) are common with corrugated steel and concrete slab decking. Spacings up to approximately 8 ft (2.4 m) are typical for roof decking systems.

BEAM AND GIRDER CONFIGURATION

The orientation of beams and girders in a floor or roof framing system may depend on a variety of factors. In relation to the building at large, it may be advantageous to run girders parallel to the building's shorter axis, the direction most susceptible to lateral forces. In this way, these stronger members can contribute additional lateral resistance to the building through rigid frame action.

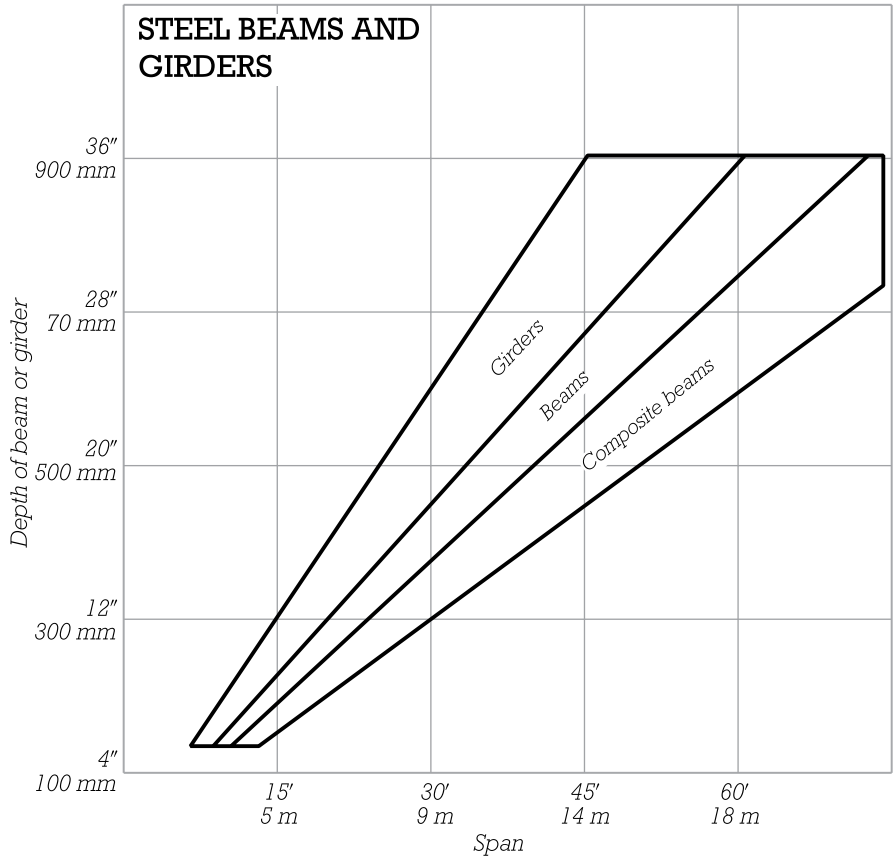
Within individual column bays, it is usually more economical to run girders in the shorter direction of a rectangular bay, allowing the lighter beams to span the longer distance. However, when cellular decking is used as part of a wiring system, beam and girder directions may be set so that the wire conduits within the decking run in preferred directions as required by communications or power distribution plans (see page 213).

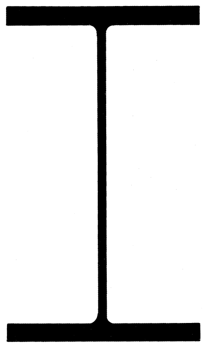


For economical framing of steel bays, the lighter beams should span 1.25 to 1.5 times the span of the heavier girders. Bay area should equal approximately 1000 ft² (95 m²).

COMPOSITE BEAMS

In composite construction, shear studs are added to the top of the floor beams. This causes the concrete deck and steel framing to act together, as a unified structural element and results in reduced beam depths. Composite construction can be more economical, particularly at longer spans. However, a thicker concrete deck may be required.





This chart is for steel wide-flange beams, composite beams, and girders. For average and light loads, read toward the right in the indicated areas. For heavy loads, read toward the left.

■ Beams or girders acting as part of a rigid frame for lateral stability may be deeper than indicated by this chart.

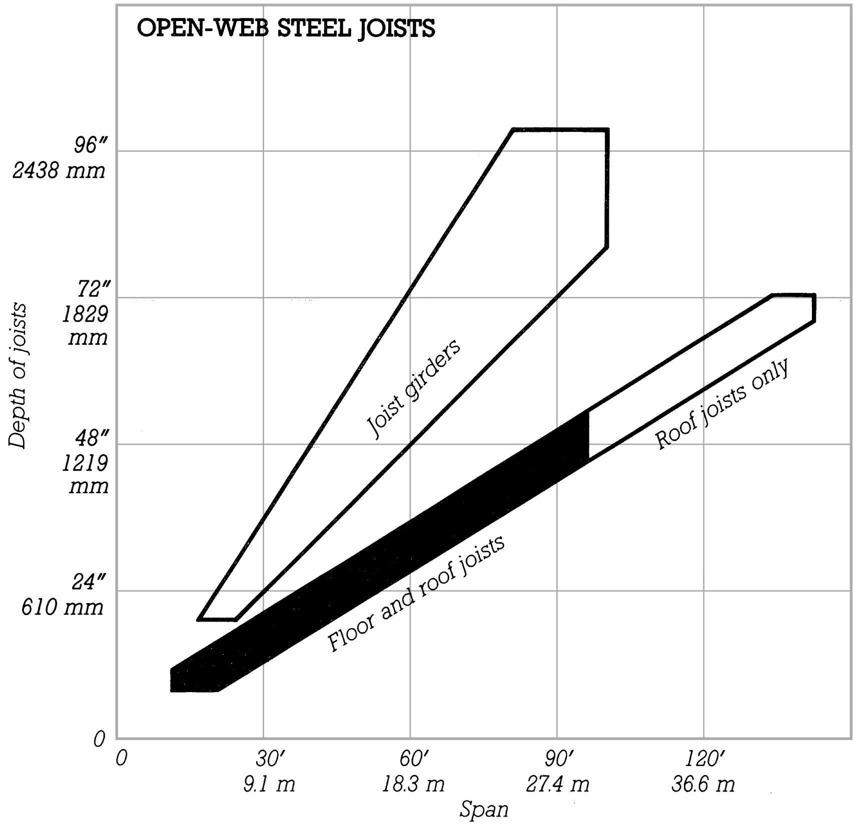
■ Standard depths of shapes come in 2-in. (50-mm) increments up to 18 in. (450 mm) deep, and in 3-in. (75-mm) increments for larger sizes.

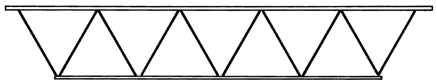
■ Widths of beams and girders range from approximately one-third to one-half the depth of the member. Heavy sections used for heavy loads or to conserve depth may be wider.

■ Depths of up to 36 in. (914 mm) are available as standard rolled sections. Deeper beams capable of longer spans may be shop-fabricated.

FIRE RESISTANCE AND STEEL BEAMS AND GIRDERS

Steel beams and girders may be used in both Combustible and Noncombustible Construction. Fire-resistance ratings of as high as 4 hours are achievable with applied fireproofing or an appropriately fire-resistive ceiling. Some building codes also allow reduced fire protection or exposed steel for roof structures that are 15 to 25 ft (4.6 to 7.6 m) or more above the floor.





This chart is for open-web steel joists and joist girders for floors and roofs. For light loads or close joist spacings, read toward the right in the indicated areas. For heavy loads or large joist spacings, read toward the left.

- Joist spacings range from 2 to 10 ft (0.6 to 3.0 m) or more, depending on the floor loads and the decking system applied over the joists.
- Joists generally come in depths of 8 to 32 in. in 2-in. increments (203 to 813 mm in 51-mm increments) and from 32 to 72 in. in 4-in. increments (from 813 to 1829 mm in 102-mm increments). Availability of sizes varies with the manufacturer.
- Joist girders come in depths of 20 to 96 in. in 4-in. increments (508 to 2438 mm in 102-mm increments).

OPEN-WEB JOIST FRAMING

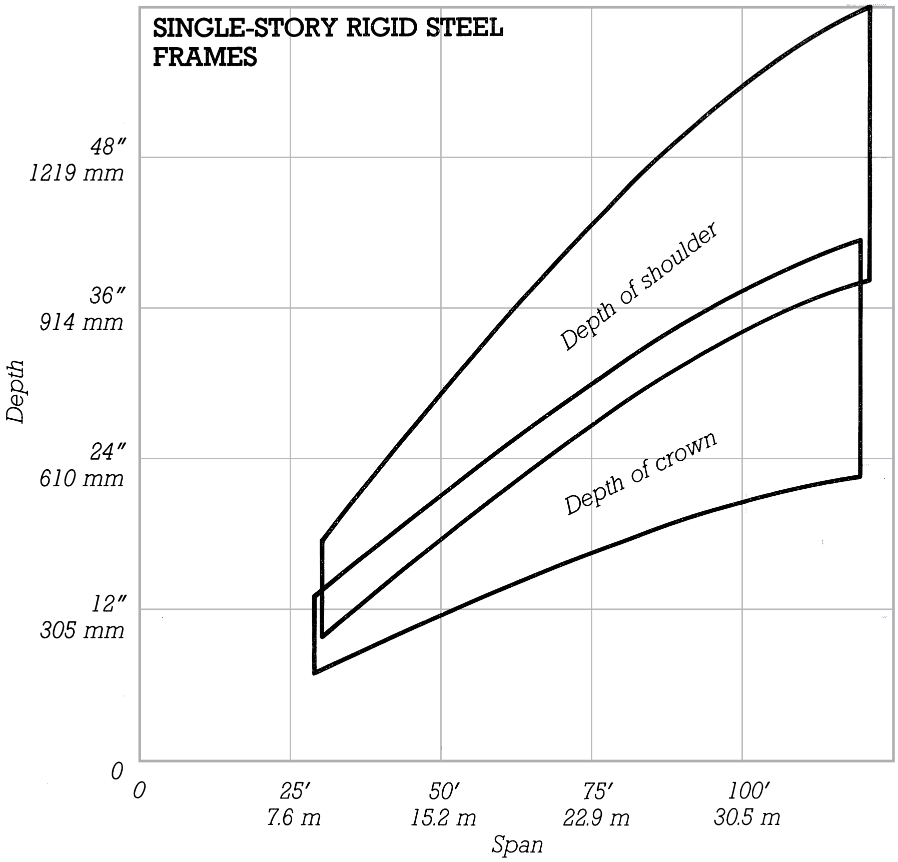
The light weight of open-web steel joists makes them an economical alternative to conventional structural steel members for spans greater than 30 to 40 ft (9 to 12 m). Where significant concentrated loads exist, open-web joists may need to be supplemented with additional structural members.

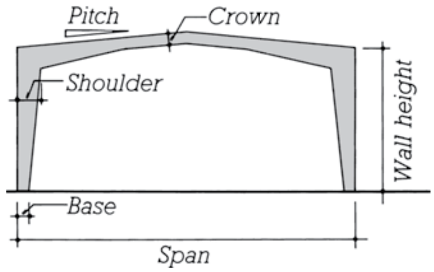
Girders used with open-web joists may be joist girders (a heavier version of an open-web joist) or conventional structural steel members. For greater loads and spans, heavy steel trusses may also be used. For rectangular bays, the joists usually span the longer direction. (See pages 104–105 for structural steel beams and girders, and page 108 for heavy steel trusses.)

A variety of proprietary composite open-web joist systems is also available. Such systems are particularly effective at overcoming the excessive flexibility sometimes encountered with conventional long-span joist systems.

FIRE RESISTANCE AND OPEN-WEB STEEL JOISTS

Open-web steel joists may be used in both Combustible and Noncombustible Construction. Fire-resistance ratings of as high as 3 hours are achievable with applied fireproofing or an appropriately fire-resistive ceiling. Some building codes also permit reduced fire protection or exposed steel for roof structures that are 15 to 25 ft (4.6 to 7.6 m) or more above the floor.





This chart is for single-story rigid steel frame structures within the dimensional limits indicated in the following list. For heavy loads, read toward the top in the indicated areas. For light loads, read toward the bottom. For other configurations, consult manufacturers.

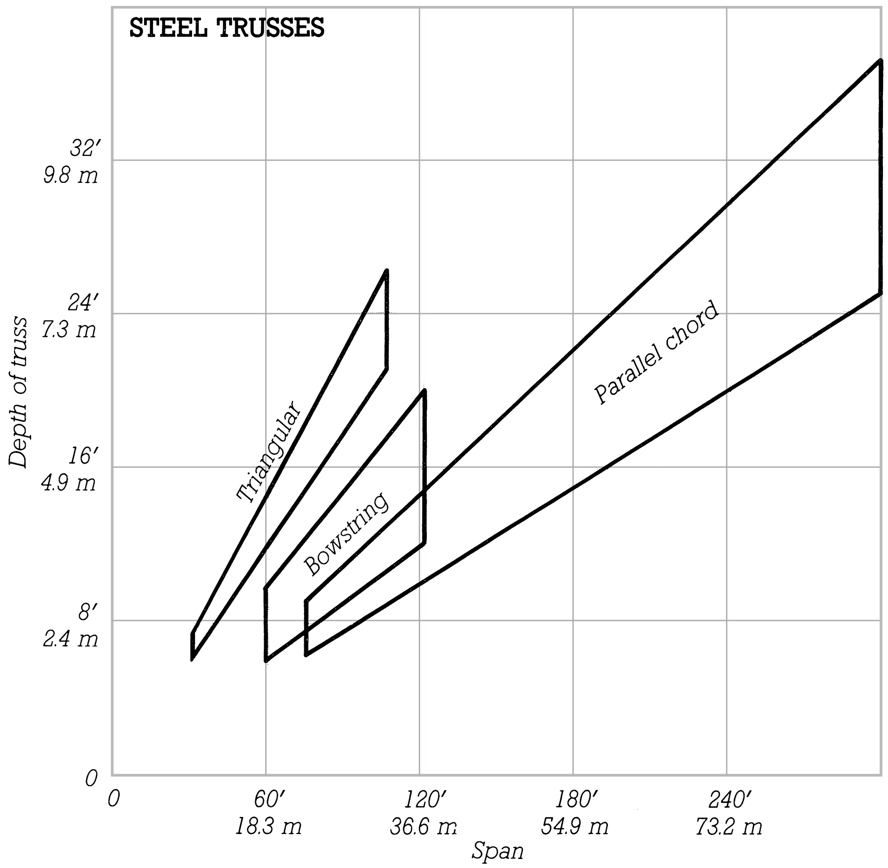
- Roof pitch: ½ : 12 to 4:12
- Wall height: 8 to 30 ft (2.4 to 9.1 m)
- Depth at base: 7 to 21 in. (180 to 535 mm)

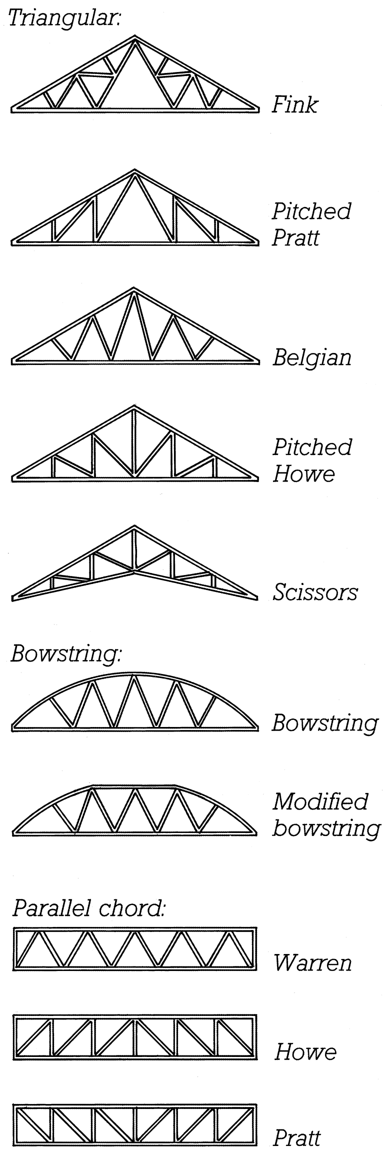
SINGLE-STORY RIGID STEEL FRAME CONFIGURATIONS AND SPANS

Single-story rigid steel framing systems come in a variety of configurations capable of clear spans exceeding 300 ft (90 m), or even further with the addition of intermediate columns. Roof pitches may range from ½ :12 to 12:12. Typical frame spacing is 20 to 25 ft (6.1 to 7.6 m), or as much as 40 ft (12 m) when used with wall and roof systems capable of spanning the greater distance between frames.

FIRE RESISTANCE AND SINGLE-STORY RIGID STEEL FRAMES

Single-story rigid steel frames may be used in both Combustible and Noncombustible Construction. Fire-resistance ratings of as high as 4 hours are achievable with applied fireproofing. Some building codes also allow reduced fire protection or exposed steel for roof structures that are 15 to 25 ft (4.6 to 7.6 m) or more above the floor.





ECONOMICAL SPAN RANGES FOR PARALLEL CHORD TRUSSES

Parallel chord trusses are most economical for spans up to 120 to 140 ft (35 to 45 m) due to the increased difficulty of shipping elements greater than 12 ft (3.7 m) deep. Triangular and bowstring trusses can be shipped at slightly greater depths. Trusses spanning 300 ft (90 m) or more may be shipped in sections and assembled on-site.

FIRE RESISTANCE AND STEEL TRUSSES

Structural steel trusses may be used in both Combustible and Noncombustible Construction. Fire-resistance ratings of as high as 4 hours are achievable with applied fireproofing or an appropriately fire-resistive ceiling. Some building codes also allow reduced fire protection or exposed steel for roof structures that are 15 to 25 ft (4.6 to 7.6 m) or more above the floor.

The chart on this page is for steel trusses fabricated from structural steel members. Because these trusses are custom designed and fabricated, a great variety of shapes and configurations is possible.

SITECAST CONCRETE STRUCTURAL SYSTEMS

The choice of sitecast concrete framing systems is constrained by the required spans (the spacing between walls or columns) and by the magnitude of the in-service loads. The following systems are listed in order of increasing span and load capacity. Those listed in bold type are generally the most economical within their span range.

- One-Way Solid Slab
- **Two-Way Flat Plate**
- **Two-Way Flat Slab**
- **One-Way Joist**
- Waffle Slab
- One-Way Beam and Slab
- Two-Way Beam and Slab

For lightly loaded, short-span conditions, consider systems from near the top of the list. For longer spans or heavier loads, consider systems lower down. Where cost is a primary consideration, preference should be given to those systems listed in bold type.

POSTTENSIONING

The span ranges of sitecast concrete systems can be increased by the use of posttensioned reinforcing (high-tensile-strength steel cable reinforcing within the concrete that is stretched tight after the concrete has cured). Charts for the sizing of posttensioned systems are included in this section. Posttensioning also reduces the depth of spanning members and may be desirable where floor-to-floor heights must be kept to a minimum.

The extensive use of posttensioning in a concrete structure may limit the ease with which such a structure can be modified in the future, since penetrations in slabs and beams must not interrupt the continuity of the stressed cables or surrounding concrete. This may make posttensioning an undesirable choice for buildings where significant change in program or structure must be anticipated.

ARCHITECTURAL SITECAST CONCRETE CONSTRUCTION

The inherent fire-resistive qualities of concrete construction allow concrete systems to remain exposed in completed buildings even of significant size. The process by which concrete is formed onsite, and its monolithic and plastic qualities as a finished product, also give this material unique architectural possibilities.

When designing exposed *architectural concrete*, the choice of system will have a significant impact on the building design and aesthetic and should be considered as early as possible in the design process. Factors to consider include the added cost and difficulty of achieving high levels of finish quality and dimensional accuracy with concrete, the absence of hollow spaces for the routing of concealed mechanical and electrical services, and the potential aesthetic qualities of the various forming systems, construction elements, and structural configurations.

SITECAST CONCRETE COLUMNS

CONCRETE STRENGTH AND COLUMN SIZE

The top chart on the facing page is based on 4000 psi (25 MPa) concrete with reinforcing appropriate for buildings of low to moderate height. For taller buildings or longer-span systems, the larger column sizes indicated may become uneconomical due to the increasing quantity and weight of materials required, as well as the greater encroachment on usable floor area. In these circumstances, higher-strength concrete and greater amounts of reinforcing can be used to maintain columns of more practical size. To adjust the column size in the top chart on the facing page for variations in concrete strength, use the factors in the table to the right.

Concrete Strength		Multiply Column Size by:
6000 psi	(40 MPa)	0.80
8000 psi	(48 MPa)	0.70
12,000 psi	(85 MPa)	0.60
16,000 psi	(110 MPa)	0.50

MINIMUM COLUMN SIZES

Square concrete columns should not be less than 10 in. (250 mm) on each side. Rectangular columns should not be less than 8 × 10 in. (200 × 250 mm), with the wider side never more than three times the width of the shorter side. Round columns should not be less than 12 in. (150 mm) in diameter.

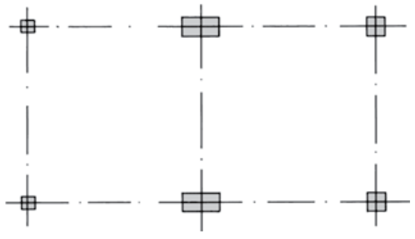
For columns used with any of the two-way slab systems listed in the table to the right, see the pages indicated for additional limits on minimum column size in relation to the depth of the slab.

Systems	Pages
Sitecast Concrete Two-Way Flat Plate	120–121
Sitecast Concrete Two-Way Flat Slab	122–123
Sitecast Concrete Waffle Slab	124–125

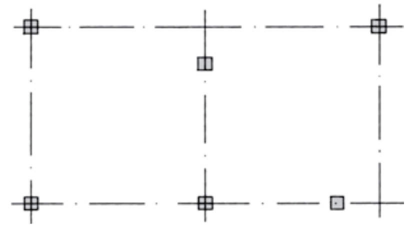
ECONOMICAL CONCRETE COLUMN DESIGN

Column sizes should change as little as possible throughout a building. Where loads vary, column size can be held constant while its load capacity is varied by adjusting the strength of the concrete mix or the amount of steel reinforcing. In multistory buildings, column sizes should generally not vary between floors. Rather, higher-strength concrete or greater quantities of reinforcing are used in lower-story columns to compensate for the larger loads on those columns. Where size variations cannot be avoided, changing only one dimension of a column at a time, in multiples of 2-in. (50-mm) increments, is preferred.

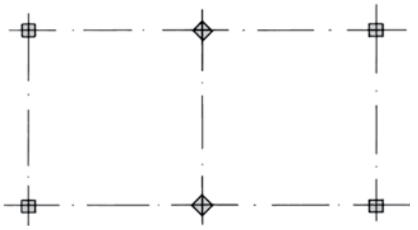
Columns should be as uniformly spaced as possible. Irregular column placements make formwork more expensive. Rectangular or square columns should conform to standard orthogonal alignments. Deviations from the normal complicate formwork where the column and the slab meet. See the diagrams to the right.



VARIATIONS IN COLUMN SIZE



VARIATIONS IN COLUMN PLACEMENT

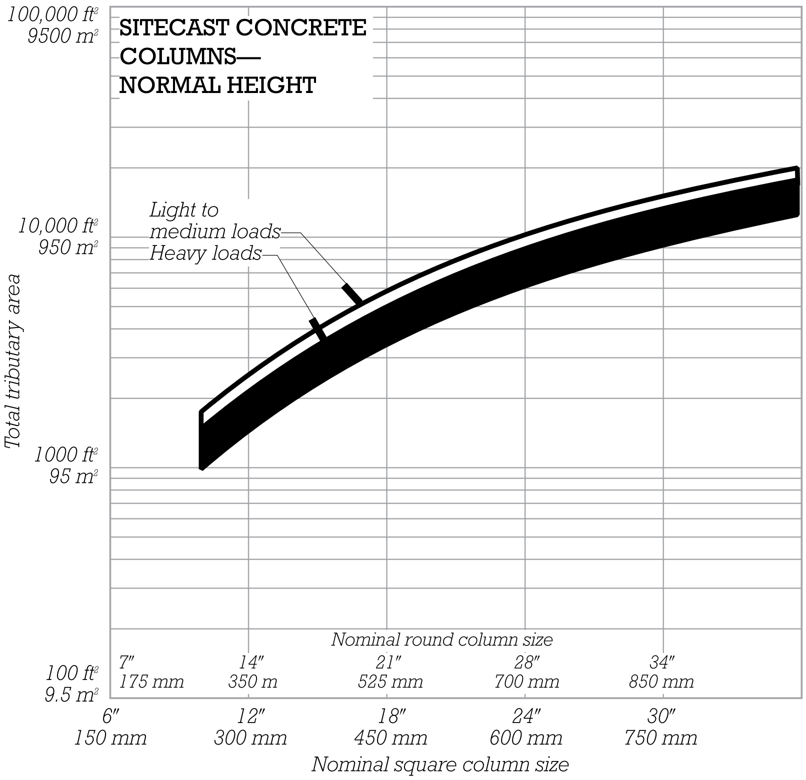


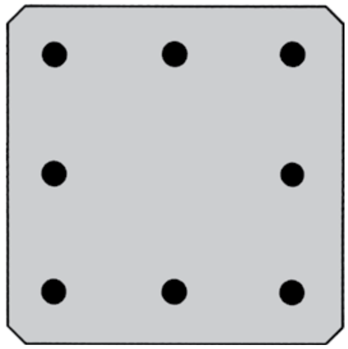
VARIATIONS IN COLUMN ALIGNMENT

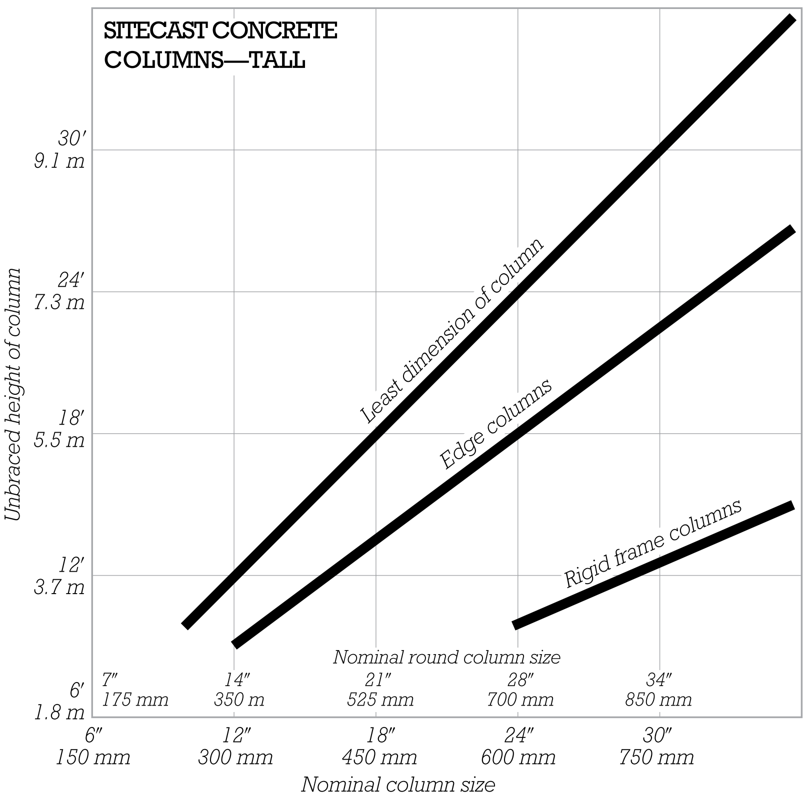
FIRE RESISTANCE AND SITECAST CONCRETE COLUMNS

Sitecast concrete columns may be used in both Combustible and Noncombustible Construction. Their fire resistance varies with the composition of the concrete and the placement of reinforcing. For preliminary design, you may assume that a 1-hour fire-resistance rating can be achieved with columns not less than 8 in. (200 mm) on a side. Fire-resistance ratings of 2, 3, and 4 hours can be achieved with columns 10 in. (250 mm), 12 in. (300 mm), and 14 in. (350 mm) in minimum dimension, respectively.

SITECAST CONCRETE COLUMNS







The top chart is for sitecast concrete columns with a clear height of up to 10 ft (3.0 m). Clear height is the distance from the top of the slab below the column to the underside of the slab or beam above. For lightly to moderately loaded columns, read in the upper open area of the curve. For heavily loaded columns, read in the lower solid area. *Total tributary area* is the summed area of the roof and all floors supported by the column.

■ For rectangular columns, select a column of area equal to the square size indicated.

■ Actual column size is equal to nominal size.

For columns with a clear height greater than 10 ft (3.0 m), read from both charts on this page, using the larger size indicated by either one. First, read along the line labeled *Least dimension of column* to determine the smallest permitted size. Columns subject to high bending forces are further restricted as follows: For those that are part of a rigid frame lateral force resisting system, the column's minimum size in the direction to which it is subject to bending is indicated by the line labeled *Rigid frame columns*. For columns located close to the edge of the slab it supports (within one-quarter of a span or less), the column's minimum size perpendicular to the slab edge is indicated by the line labeled *Edge columns*.

SITECAST CONCRETE WALLS

Sitecast concrete bearing walls may be used as the primary loadbearing element in a structural system or may be an integrated part of many other systems. Some of the most common uses for concrete walls include construction below grade, building structural cores, and shear walls in steel or concrete frame construction.

CONCRETE STRENGTH AND WIDTH OF WALL

The top chart on the facing page is based on 4000 psi (25 MPa) concrete with reinforcing levels appropriate for buildings of low to moderate height. For taller buildings or longer-span systems, the wider wall sizes indicated may become uneconomical due to the increasing quantity and weight of materials required, as well as the greater encroachment on usable floor area. In these circumstances, higher-strength concrete can be used to maintain walls of more practical size. To adjust the width of walls in the top chart on the facing page for variations in concrete strength, use the factors in the table to the right.

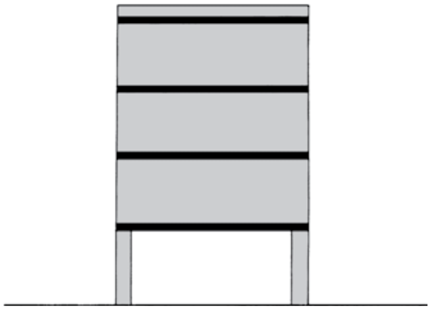
Concrete Strength		**Multiply Wall Width by:**
6000 psi	(40 MPa)	0.80
8000 psi	(55 MPa)	0.65
12,000 psi	(85 MPa)	0.45
16,000 psi	(100 MPa)	0.35

DESIGN OF SITECAST CONCRETE WALLS

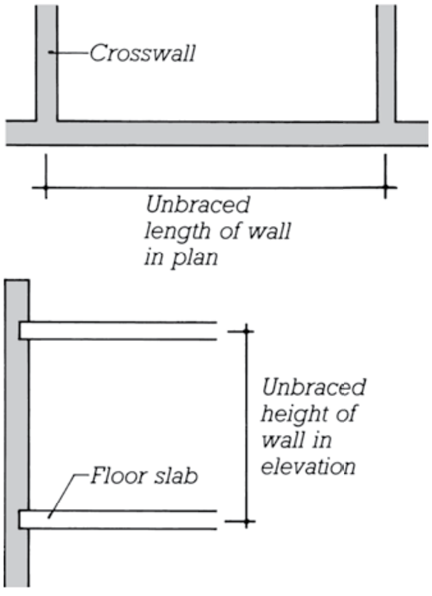
Nonloadbearing walls may be as thin as 4 in. (100 mm). Loadbearing sitecast concrete walls 6 in. (150 mm) wide should be used for light loads and one-story structures only. Loadbearing walls 8 in. (200 mm) wide are suitable for low-rise structures and light to medium loads. For taller structures and heavy loads, use concrete walls 10 in. (250 mm) or wider. Vary wall thickness as little as possible. Where necessary, changes in thickness should be in 2- or 4-in. (50- or 100-mm) increments.

Loadbearing wall locations should be consistent from floor to floor and continuous to the building foundation. Where it is desirable to omit bearing walls on a lower floor, an economical alternative may be to design the wall above to act as a deep beam spanning between columns at each end. The space between columns may then remain open. Such wall beams may economically span to 20 to 30 ft (6 to 9 m).

Sitecast concrete walls are frequently used as shear walls to help stabilize buildings against wind and seismic forces. The guidelines for minimum widths of walls provided on these two facing pages should normally result in walls with sufficient capacity to also act as shear walls where required. In addition, conventional concrete shear walls should be proportioned so that their total height, from foundation to top of wall, is no more than four times the length of the wall. Nevertheless, with special design, taller, more slender walls are also practical. For more information on designing building lateral stability systems, see pages 41–43.



Bearing walls may act as deep beams to span across openings below.

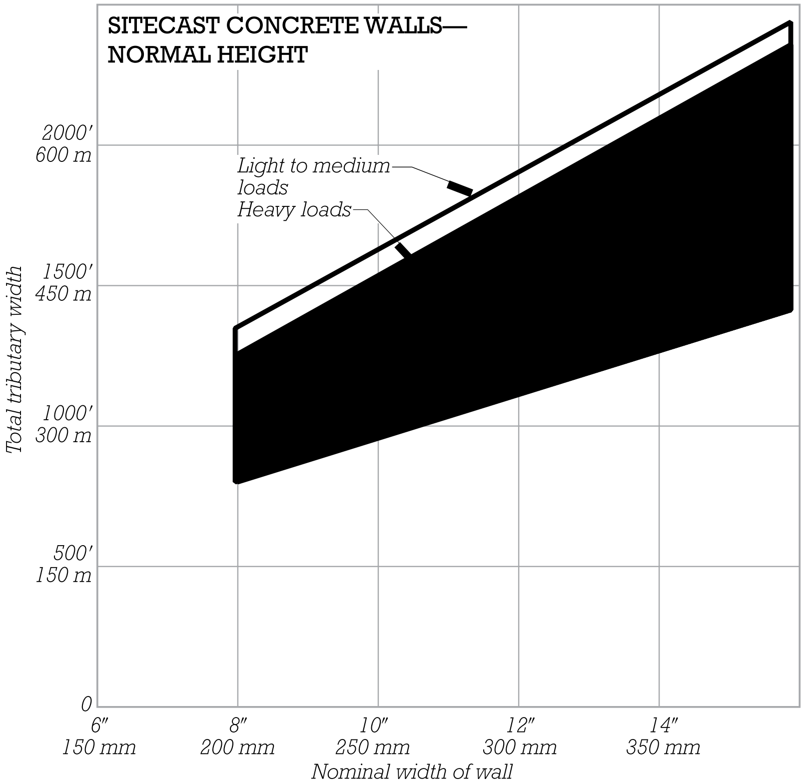


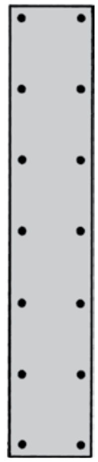
UNBRACED HEIGHT OR LENGTH OF CONCRETE WALLS

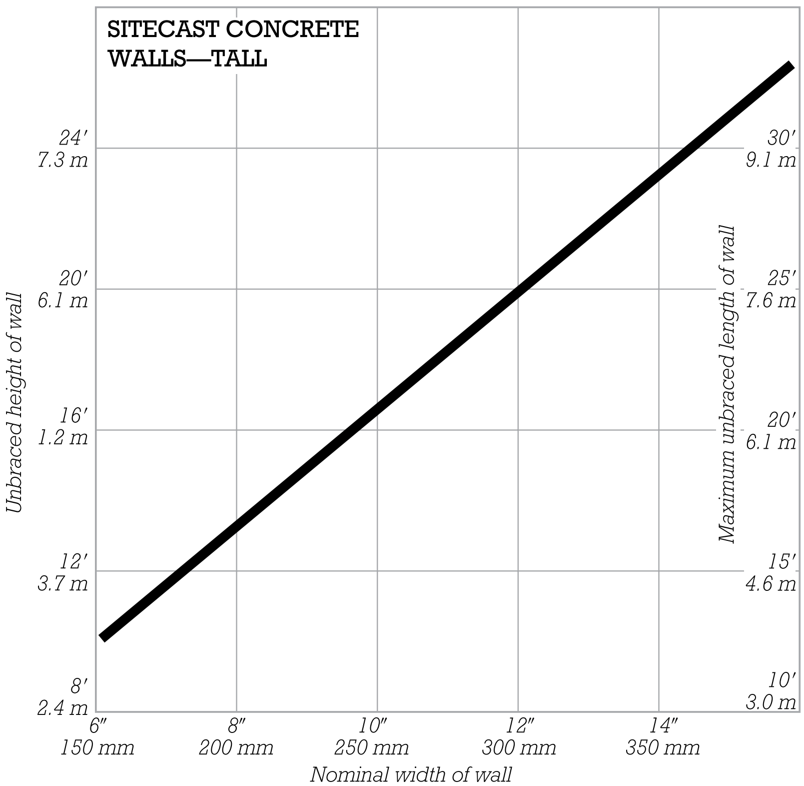
FIRE RESISTANCE AND SITECAST CONCRETE WALLS

Sitecast concrete walls may be used in both Combustible and Noncombustible Construction. Their fire resistance varies with the composition of the concrete and the placement of reinforcing. For preliminary design, assume that a 1-hour fire-resistance rating can be achieved with a wall 4 in. (100 mm) in width. Fire-resistance ratings of 2, 3, and 4 hours can be achieved with walls 5 in. (125 mm), 6 in. (150 mm), and 7 in. (175 mm) in width, respectively.

SITECAST CONCRETE WALLS







The top chart is for sitecast concrete walls up to 10 ft (3.0 m) tall between floors. For light loads, read in the upper open area of the curve. For medium to heavy loads, read in the lower solid area. *Total tributary width* is one-half the span of one floor supported by the wall multiplied by the number of floors and the roof above.

■ Actual width of the wall is equal to its nominal width.

For walls greater than 10 ft (3.0 m) in height, read from both charts on this page, using the larger size indicated by either chart. *Unbraced height of wall* is the vertical distance between floors or other supports that brace the wall laterally against buckling along the wall's vertical axis.

Use the lower chart to also check the *Maximum unbraced length of wall*, the maximum permissible length of the wall between crosswalls, pilasters, or other elements bracing the wall along its horizontal axis. (See the diagrams on the facing page.) Starting with the wall's nominal width, read up to the line and then across to the scale on the right-hand side of the chart to determine the wall's maximum length between supports.

ECONOMICAL BEAM DESIGN

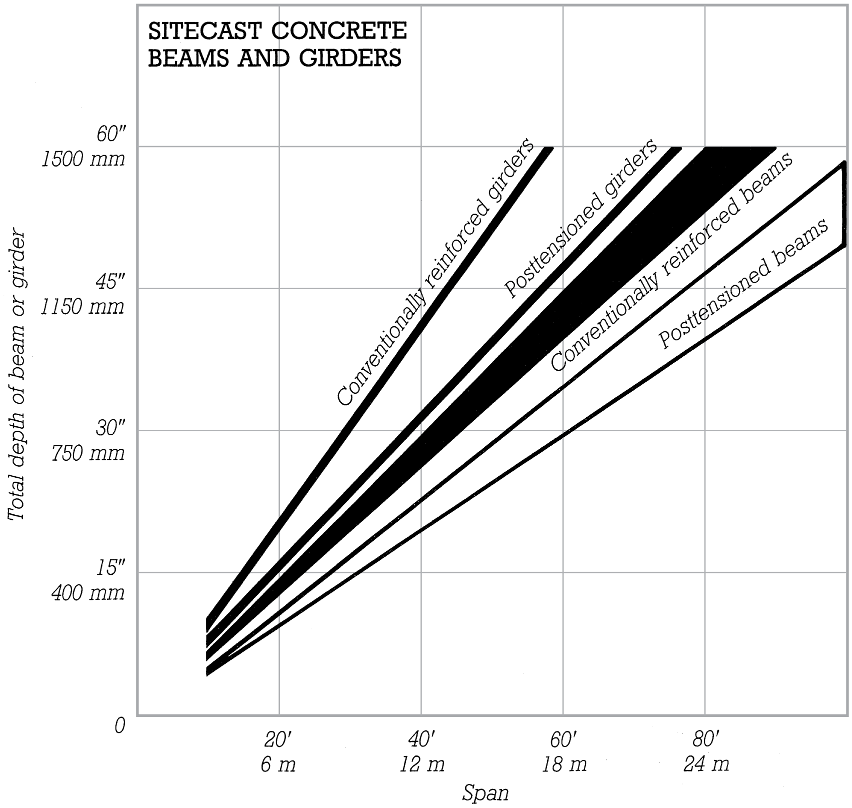
Sitecast concrete is a versatile building material with unique expressive potential. While it can be used in a great variety of ways, for maximum economy, consider the following guidelines.

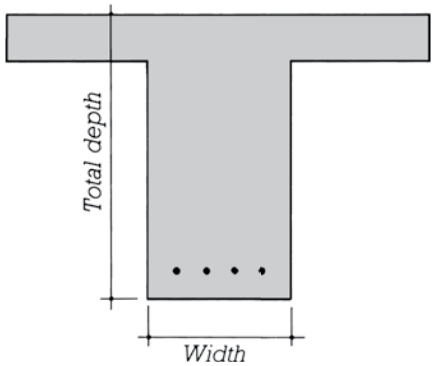
Maintain uniform sizes of beams throughout the building, to the greatest extent possible. Size the beam with the longest span, using the chart on the facing page. Beams with shorter spans can often be the same size with reduced reinforcement. Use beam widths equal to or greater than the widths of the columns supporting them.

In some systems, an economical alternative to conventionally sized beams and girders is wide, shallow beams called *slab bands* (for solid slab construction) or *joist bands* (for one-way joist construction). Savings in floor-to-floor heights are possible with the reduced depth of beam, and formwork costs are reduced. The depth of the slab itself may be reduced as well, since with broader beams, the span of the slab between beams is lessened. See pages 116–117 for slab bands, and pages 118–119 for joist bands.

FIRE RESISTANCE AND SITECAST CONCRETE BEAMS AND GIRDERS

Sitecast concrete beams and girders may be used in both Combustible and Noncombustible Construction. Their fire-resistance ratings vary with the composition of the concrete and the placement of reinforcing. For preliminary design, concrete beams and girders with a width of 10 in. (250 mm) may have an assumed fire-resistance rating of 4 hours.





This chart is for sitecast concrete beams and girders, either conventionally reinforced or posttensioned. For lightly to moderately loaded beams, read toward the right in the indicated areas. For heavy loads or simple spans, read toward the left.

■ For girders, read on the lines indicated.

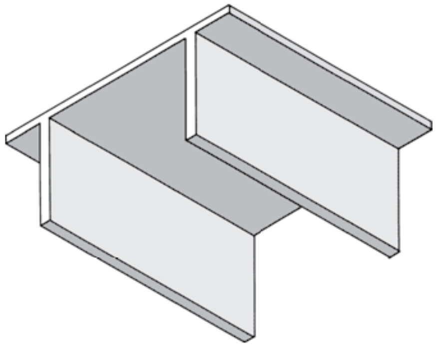
■ Size beam depths in even 2-in. (50-mm) increments.

■ *Total depth of beam or girder* is measured from the bottom of the beam to the top of the slab.

■ Normal beam widths range from one-third to one-half of the beam depth. Use beam widths in multiples of 2 or 3 in. (50 or 75 mm).

SITECAST CONCRETE ONE-WAY SOLID SLAB

One-way solid slab construction supported by bearing walls is the least expensive sitecast concrete framing system for short spans and light loads. It is a popular concrete construction system for multiple-dwelling building types such as apartments or hotels, where the regular spacing of bearing walls is easily coordinated with the layout of the small, uniformly arranged rooms typical of these buildings.



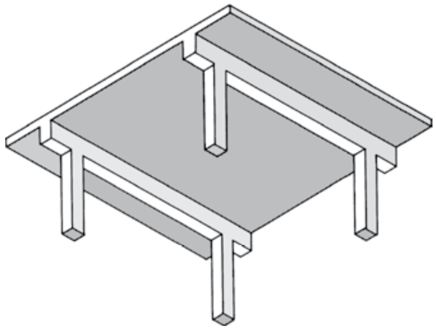
ONE-WAY SOLID SLAB WITH BEARING WALLS

ONE-WAY BEAM AND SLAB SYSTEMS

The addition of beams and girders to one-way solid slab construction can increase the load capacity and span range of the system and eliminate the need for regularly spaced walls in the building plan. However, with the increased complexity of beam and girder formwork, the beam and slab system is one of the most expensive of all sitecast concrete systems. One-way beam and slab construction is usually economical only where long spans or high loads must be accommodated, such as with industrial uses or in areas of high seismic risk.

Slab bands can be an economical alternative to conventional deeper beams when beams are used. Savings in floor-to-floor heights are possible with the reduced beam depths, and formwork costs are reduced. The depth of the slab itself may be reduced as well, since with the broader beams, the span of the slab between the beams is lessened.

Maximum repetition of standard sizes increases the economy of slab and beam systems. Wherever possible, beam depths should be sized for the longest spans, and then the same depths should be used throughout. Beam widths and spacings, slab depths, and column sizes and spacings should all vary as little as possible within the structure.

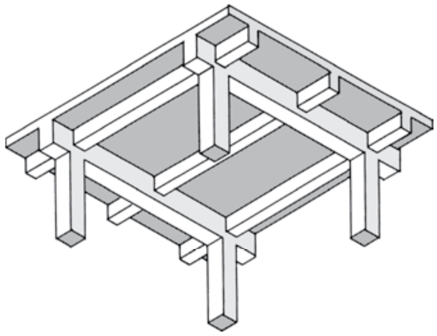


ONE-WAY SOLID SLAB WITH BEAMS

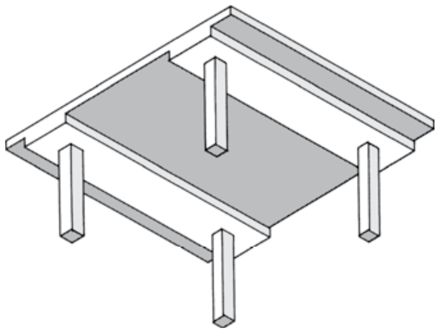
FIRE RESISTANCE AND ONE-WAY SOLID SLAB CONSTRUCTION

Sitecast concrete one-way solid slabs may be used in both Combustible and Noncombustible Construction. Their fire resistance varies with the composition of the concrete and the placement of reinforcing. Use the following guidelines for preliminary design:

To achieve a 3-hour fire-resistance rating, a solid slab must be at least 6.5 in. (165 mm) thick. For a 2-hour rating, the minimum thickness is 5 in. (127 mm); for 1½ hours, 4.5 in. (114 mm); and for 1 hour, 3.5 in. (89 mm).

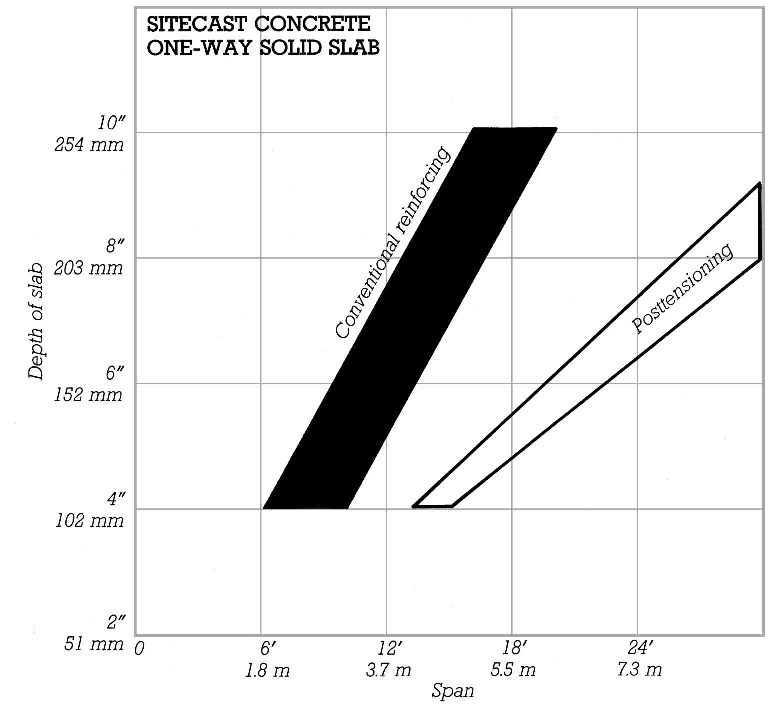


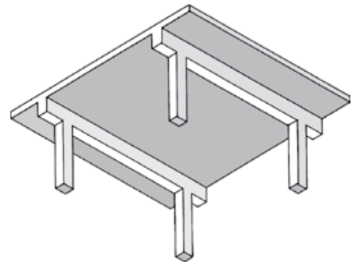
ONE-WAY SOLID SLAB WITH BEAMS AND GIRDERS



ONE-WAY SOLID SLAB WITH SLAB BANDS

SITECAST CONCRETE ONE-WAY SOLID SLAB

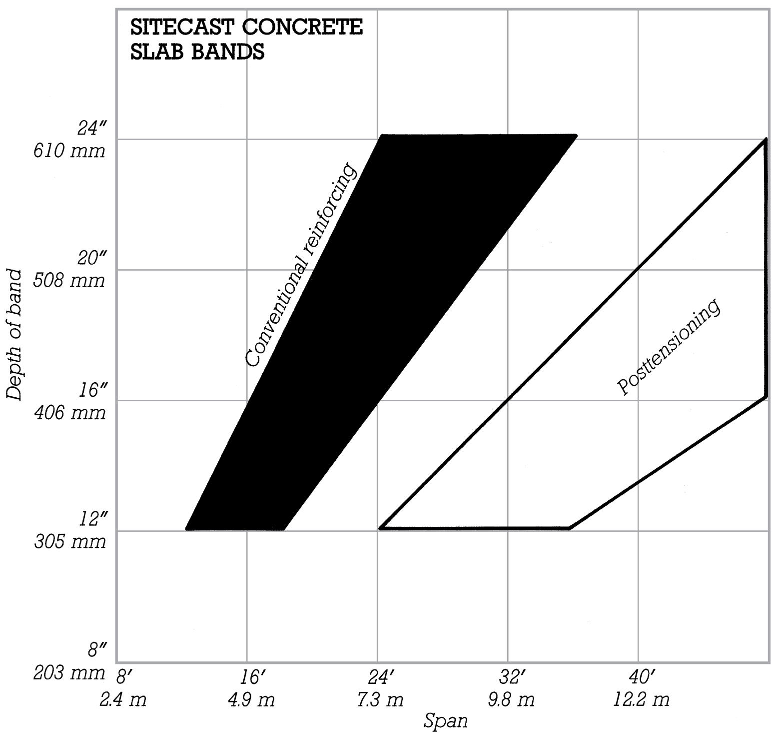


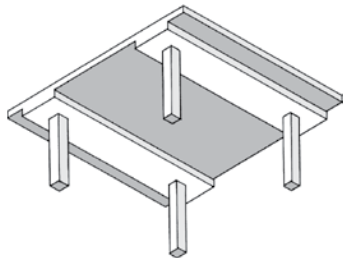


The top chart is for sitecast concrete one-way solid slab construction, either conventionally reinforced or posttensioned. For light to medium loads, read toward the right in the indicated areas. For heavy loads, read toward the left.

■ Size slab depth up to the nearest ½ in. (13 mm).

■ For the sizing of concrete beams, see pages 114–115.





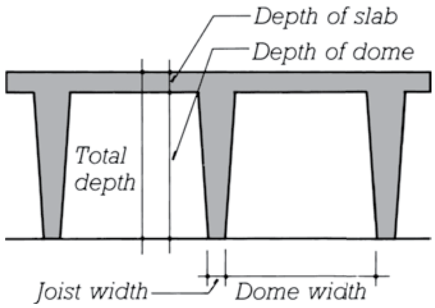
The bottom chart is for concrete slab bands—deep, wide beams that can be used with one-way solid slab construction. For light loads, read toward the right in the indicated areas. For heavy loads, read toward the left.

■ Size beam depths to the nearest inch (25 mm) and widths to the nearest foot (300 mm).

■ Typical widths for slab bands range from one-sixth to one-third the span of the slab between the beams. For slab bands that are relatively deep or that span short distances, choose a narrow width. For slab bands that are relatively shallow or that span long distances, choose a wider width.

SITECAST CONCRETE ONE-WAY JOISTS

One-way joist construction is an economical system for heavy loads or relatively long spans. This system is also sometimes desirable for the distinctive appearance of the underside of the slab, which may be left exposed in finished construction.



ONE-WAY JOISTS

JOIST LAYOUT

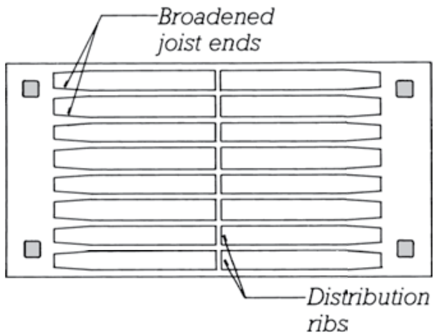
The spacing of joists depends on the widths of the pans and the joists. Standard pan widths are 20 and 30 in. (508 and 762 mm). Joists typically range in width from 5 to 9 in. (127 to 229 mm). A 6-in. (152-mm)-wide joist may be assumed for preliminary purposes.

In medium- and light-load applications, alternate joists may be omitted for greater economy. This system, called *wide module* or *skip joist* construction, is economical for spans of up to approximately 40 ft (12 m). In some instances, joist spacing may be increased to as much as 9 ft (2.7 m).

In long-span or heavy-load applications, joists may be broadened 2 to 2½ in. (50 to 65 mm) over the last 3 ft (1 m) toward their ends, for increased shear capacity.

For joist spans of greater than 20 ft (6.1 m), distribution ribs running perpendicular to the joists are required. These ribs are 4 in. (102 mm) wide and the same depth as the joists. For longer spans, allow a maximum of 15 ft (4.6 m) between evenly spaced lines of ribs.

The economy of this system depends on the maximum repetition of standard forms and sizes. Depths, thicknesses, and spacings should vary as little as possible.

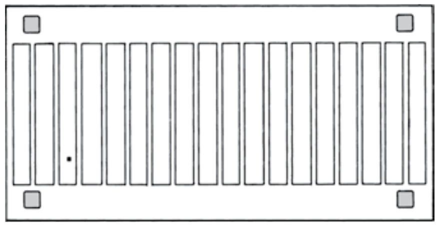


Joist bands usually run the shorter direction in rectangular bays.

JOIST BANDS

The use of joist bands the same depth as the joists is a highly economical alternative to conventional deeper beams. This system reduces building height, speeds construction, and simplifies the installation of building utilities. In some instances, it may even prove economical to use a joist system deeper than otherwise necessary, in order to match the required depth of the joist bands.

With rectangular column bays and normal to heavy loads, joist bands should usually run in the shorter direction.



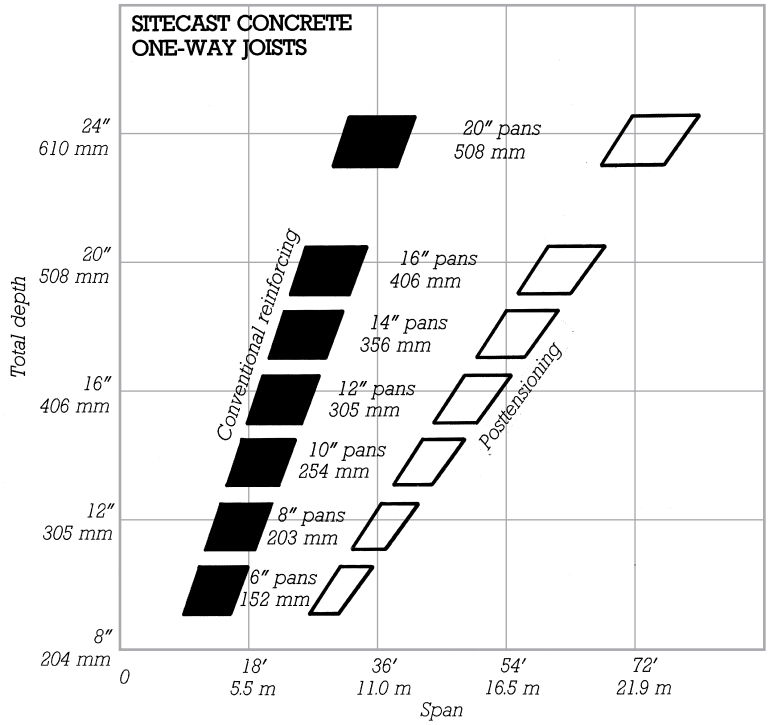
With light loads, it may be more economical to run joist bands in the long direction in a rectangular bay.

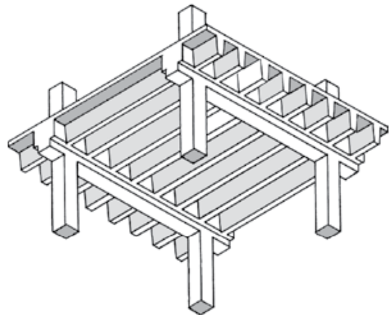
FIRE RESISTANCE AND ONE-WAY JOIST CONSTRUCTION

Sitecast concrete one-way joists may be used in both Combustible and Noncombustible Construction. Their fire resistance varies with the composition of the concrete and the placement of reinforcing. Use the following guidelines for preliminary design:

A slab that is 3 in. (76 mm) deep between joists has a fire-resistance rating of 0 to 1½ hours. A 4½-in. (114-mm)-deep slab provides 1½ to 3 hours of fire protection. For higher fire-resistance ratings, the slab thickness may be increased, fireproofing materials may be applied to the underside of the joists and slab, or an appropriately fire-resistive ceiling may be used.

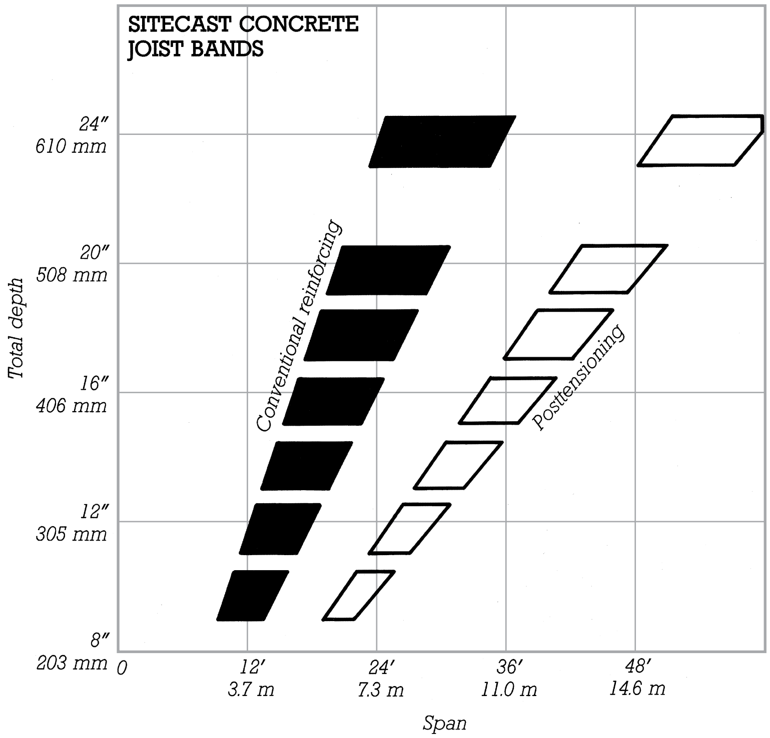
SITECAST CONCRETE ONE-WAY JOISTS

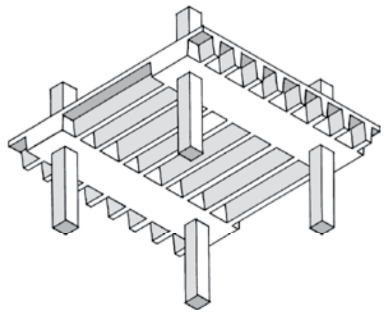




The top chart is for sitecast concrete one-way joist construction, either conventionally reinforced or posttensioned. For light loads, read toward the right in the indicated areas. For heavy loads, read toward the left.

■ *Total depth* is measured from the bottom of the joist to the top of the slab. (See the diagram on the facing page.) Depths are indicated on the chart for slabs of 3 to 4½ in. (76 to 114 mm) deep with standard pan sizes. The choice of the slab depth usually depends on the required fire-resistance rating for the system.





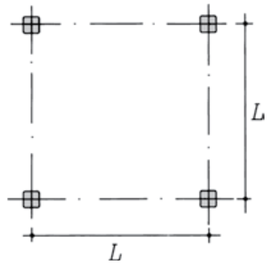
The bottom chart is for concrete joist bands—deep, wide beams used with the one-way joist system. For light loads, read toward the right in the indicated areas. For heavy loads, read toward the left.

■ For economy of formwork, use a joist band of the same depth as the joists.

■ Typical widths for joist bands range from 1 to 6 ft (0.3 to 1.8 m).

SITECAST CONCRETE TWO-WAY FLAT PLATE

Two-way flat plate construction is one of the most economical concrete framing systems. This system can span farther than one-way slabs, and the plain form of the slab makes it simple to construct and easy to finish. This system is a popular choice, for example, for apartment and hotel construction, where it is well suited to the moderate live loads, and the flexibility of its column placements permits greater ease of unit planning and layout than with a one-way system.



SQUARE BAYS

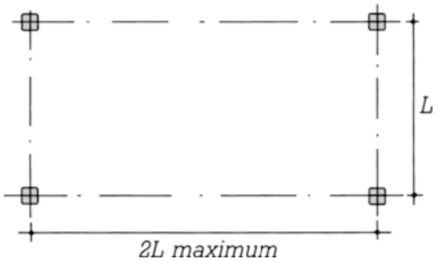
COLUMN LAYOUTS FOR FLAT PLATE CONSTRUCTION

For maximum economy and efficiency of the two-way structural system, the following guidelines on column placement should be followed whenever possible:

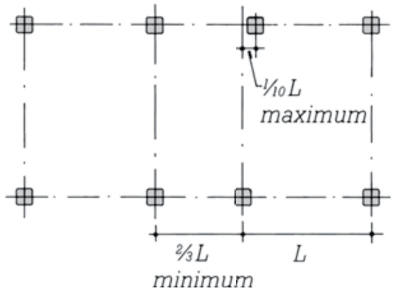
Column bays are most efficient when square or close to square. When rectangular bays are used, the sides of the bays should differ in length by a ratio of no more than 2:1.

Individual columns may be offset by as much as one-tenth the span from regular column lines. (Columns on floors above and below an offset column must also be equally offset to maintain a vertical alignment of columns.)

Successive span lengths should not differ by more than one-third of the longer span. Slabs should also span over at least three bays in each direction.



RECTANGULAR BAYS



COLUMN OFFSETS AND BAY SIZE VARIATIONS

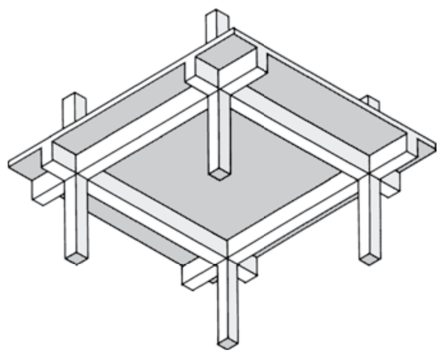
TWO-WAY SLAB AND BEAM CONSTRUCTION

Two-way slab and beam construction uses beams to support the slab between columns. The high construction costs of this system make it economical only for long spans and heavy loads, such as in heavy industrial applications, or where high resistance to lateral forces is required. For preliminary sizing of slab depths, read from the area for posttensioned construction in the chart on the facing page.

FIRE RESISTANCE AND TWO-WAY FLAT PLATE CONSTRUCTION

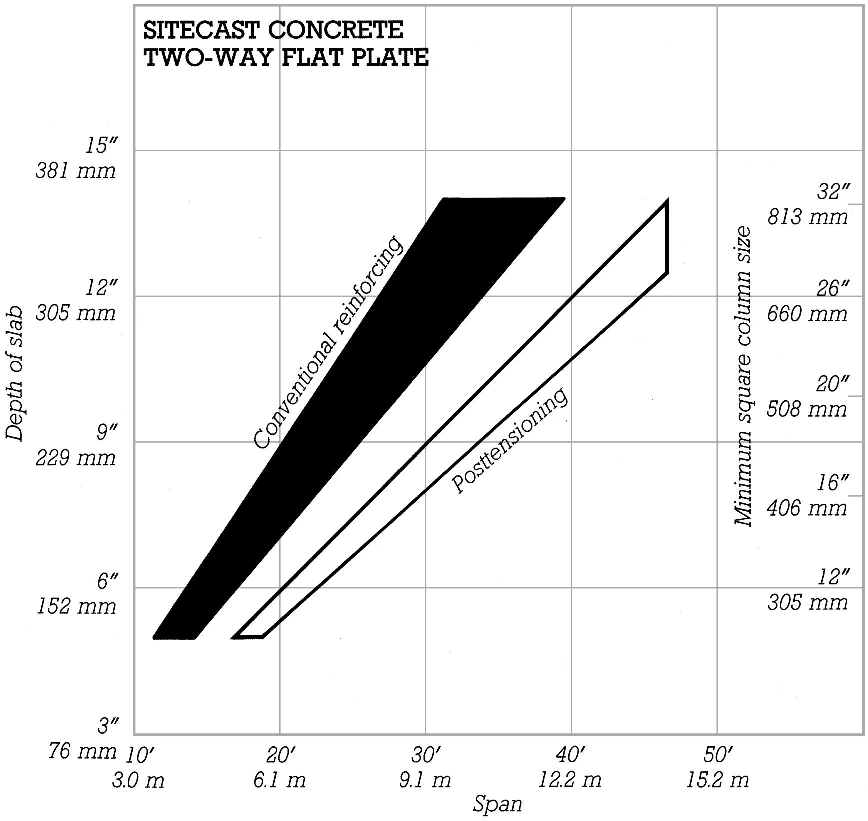
Sitecast concrete two-way flat plate construction may be used in both Combustible and Noncombustible Construction. Its fire resistance varies with the composition of the concrete and the placement of reinforcing. Use the following guidelines for preliminary design:

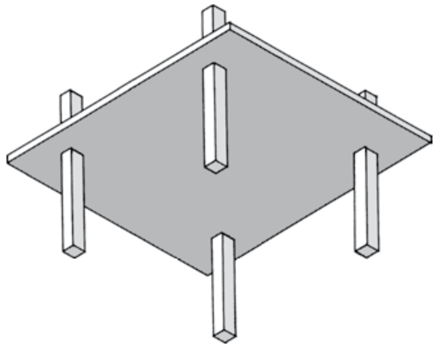
To achieve a 3-hour fire-resistance rating, the slab must be at least 6.5 in. (165 mm) thick. For a 2-hour rating, the minimum thickness is 5 in. (127 mm); for 1½ hours, 4.5 in. (114 mm); and for 1 hour, 3.5 in. (89 mm).



TWO-WAY SLAB AND BEAM CONSTRUCTION

SITECAST CONCRETE TWO-WAY FLAT PLATE





This chart is for sitecast concrete flat plate construction, either conventionally reinforced or posttensioned. For medium to light loads, read toward the right in the indicated areas. For heavy loads, read toward the left.

■ For rectangular column bays, use the span of the longer of the two sides of the bay in reading from this chart.

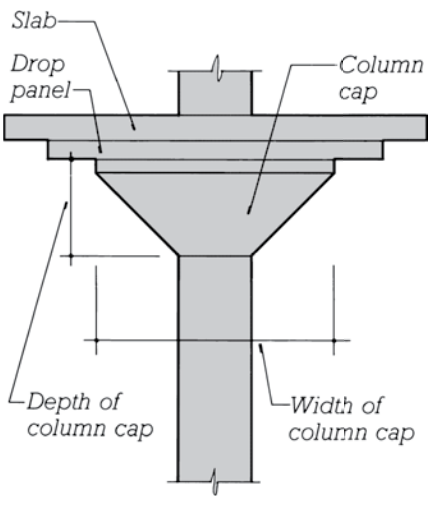
■ Size slab depth to the nearest ½ in. (10 mm).

COLUMN SIZES FOR FLAT PLATE CONSTRUCTION

The shallow depth of the junction between the slab and the column in flat plate construction restricts the minimum column size in this system. The right-hand scale on the chart above provides minimum square column sizes for various slab thicknesses. The required minimum column sizes for this system also depend on the applied loads on the structure. For light loads, reduce the indicated column size by 2 in. (50 mm). For heavy loads, increase the column size by 2 to 4 in. (50 to 100 mm).

SITECAST CONCRETE TWO-WAY FLAT SLAB

The two-way flat slab system is distinguished from flat plate construction by the strengthening of the column-to-slab junction, such as in the form of drop panels and/or column caps. Flat slab construction is an economical alternative to flat plate construction for heavier loads and longer spans. It also has increased resistance to lateral forces, and in some circumstances may permit smaller columns than flat plate construction. However, the drop panels and column caps used in this system result in increased construction costs and greater overall floor depths than with flat plate construction.



DROP PANELS AND COLUMN CAPS

DROP PANELS, COLUMN CAPS, AND SHEARHEADS

All flat slab construction requires some form of strengthening at the column-to-slab junction. Most commonly this is accomplished with the addition of *drop panels*, a deepening of the slab in the column region.

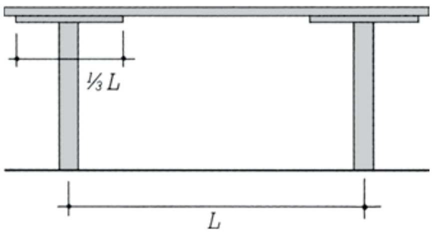
Alternatively, *column caps*, a widening of the columns toward their tops, may be used in place of drop panels where the loads on the slab are light, or in conjunction with drop panels where loads are very high. Where all such formed elements are considered undesirable, special arrangements of steel reinforcing in the slab, termed *shearheads*, may be a feasible alternative to these methods.

The minimum size for drop panels is a width of one-third the span of the slab and a total depth of one and one-fourth times the depth of the slab. For heavy loads, greater panel sizes may be required.

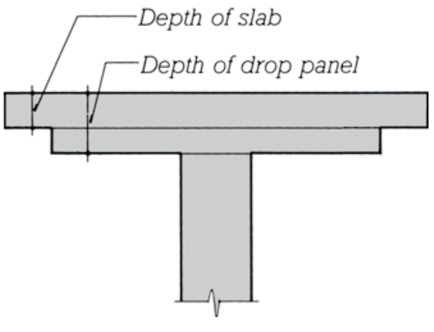
For maximum economy, keep all drop panels the same dimensions throughout the building. The difference in depth between the slab and the drop panels should be equal to a standard lumber dimension. The edges of drop panels should be a minimum of 16 ft 6 in. (5.0 m) apart to utilize standard 16-ft (4.9-m) lumber in the formwork.

When column caps are used, their overall width should be eight to 10 times the slab depth. Column caps are commonly either tapered or rectangular in profile, but should be approximately half as deep as their width at the top.

The addition of beams to flat slab construction can increase the load capacity and span range of the system, though with increased costs.



DROP PANEL WIDTH



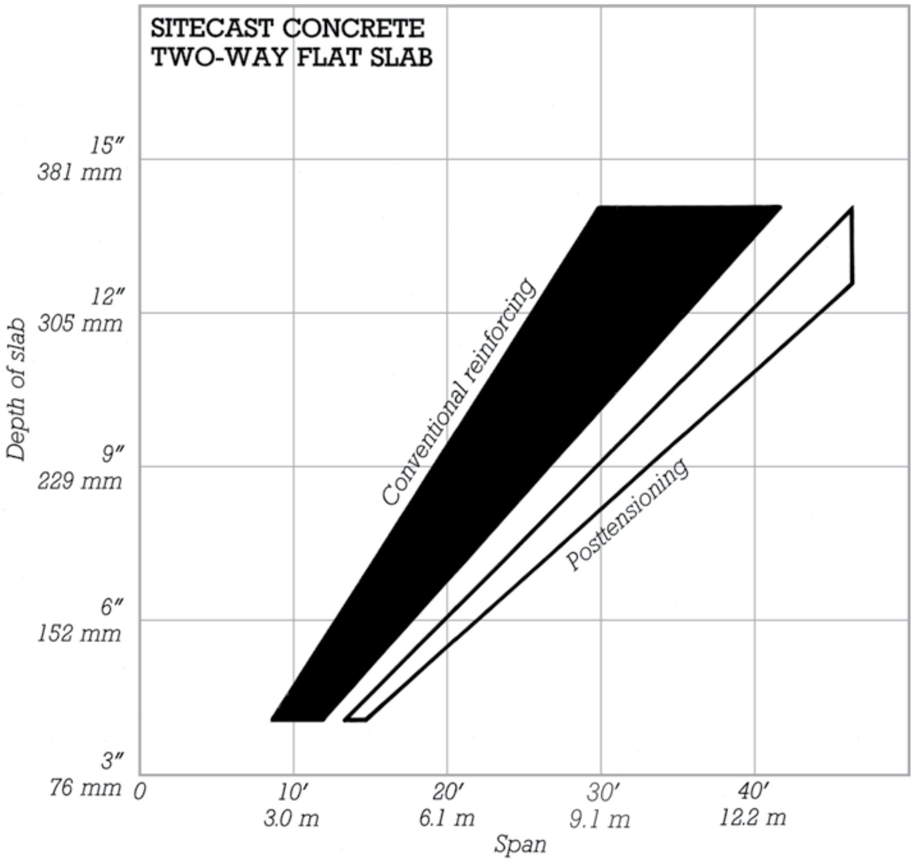
DROP PANEL DEPTH

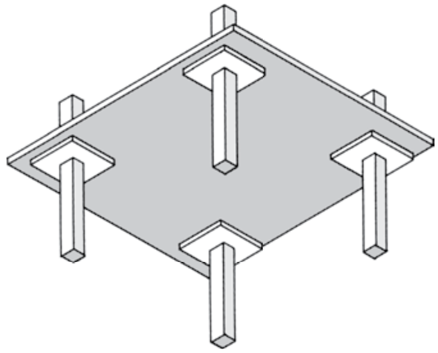
FIRE RESISTANCE AND TWO-WAY FLAT SLAB CONSTRUCTION

Sitecast concrete two-way flat slab construction may be used in both Combustible and Noncombustible Construction. Its fire resistance varies with the concrete composition and the placement of reinforcing. Use the following guidelines for preliminary design:

To achieve a 3-hour fire-resistance rating, the slab must be at least 6.5 in. (165 mm) thick. For a 2-hour rating, the minimum thickness is 5 in. (127 mm); for 1½ hours, 4.5 in. (114 mm); and for 1 hour, 3.5 in. (89 mm).

SITECAST CONCRETE TWO-WAY FLAT SLAB





This chart is for concrete two-way flat slab construction, either conventionally reinforced or posttensioned. For light loads, read toward the right in the indicated areas. For heavy loads, read toward the left.

■ For rectangular column bays, use the span of the longer of the two sides of the bay in reading from this chart.

■ Size slab depth to the nearest ½ in. (10 mm).

COLUMN SIZES AND LAYOUTS FOR FLAT SLAB CONSTRUCTION

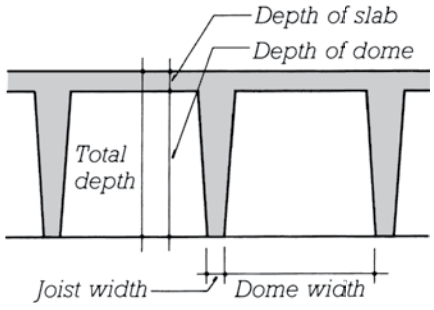
For light to moderate loads, use a minimum square column size of 12 in. (300 mm) for preliminary design. For heavier loads, larger columns or the addition of column caps may be required. Column size may be increased by 4 to 12 in. (100 to 300 mm) for extremely heavy loads.

For rectangular columns, use a column whose area is equal to that of the recommended square column size. For round columns, use a column diameter one-third greater than the recommended square column size. Column sizes may also need to be increased in multistory buildings or for columns taller than 12 ft (3.7 m). See pages 110–111 to check column sizes for these conditions.

For maximum economy and efficiency of the two-way structural system, column layouts for flat slab construction should adhere to the same guidelines as those described for flat plate construction. Column bays should be approximately square, and column offsets from regular lines should be minimized. See page 120 for a complete discussion of these guidelines.

SITECAST CONCRETE WAFFLE SLAB

The concrete waffle slab (or two-way joist) system is best suited for long spans, heavy loads, and where a thicker floor system is not a disadvantage. It exhibits excellent vibration control, a consideration for some manufacturing and laboratory facilities. It may have economic advantages where concrete material costs are very high, and the underside of the waffle slab has a distinctive appearance that can be an architectural feature. However, the waffle slab requires complex formwork to construct, and in most cases, simpler, less expensive sitecast systems are preferred.



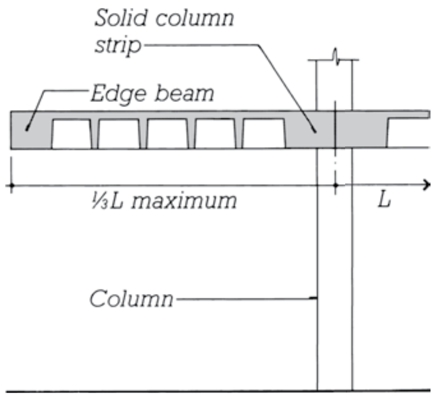
WAFFLE SLAB

RIB LAYOUT FOR WAFFLE SLAB CONSTRUCTION

Standard 19-in. (483-mm) domes are used with ribs that are 5 in. (127 mm) wide to create a 24-in. (610-mm) module. Domes of 30 in. (762 mm) are used with 6-in. (152-mm) ribs to create a 36-in. (914-mm) module. Standard domes are also available for 4- and 5-ft (1.2- and 1.5-m) modules, and other square or rectangular sizes can be specially ordered.

Solid heads must be created over columns by omitting domes in the vicinity of each column and pouring the slab flush with the bottom of the ribs. The number of domes omitted varies, increasing with longer spans and heavier loads. In some cases, solid strips may extend continuously between columns in both directions.

The economy of this system depends on the maximum repetition of standard forms and sizes. Depths, thicknesses, and spacings should vary as little as possible.



EDGE BEAMS AND CANTILEVERS

EDGE CONDITIONS

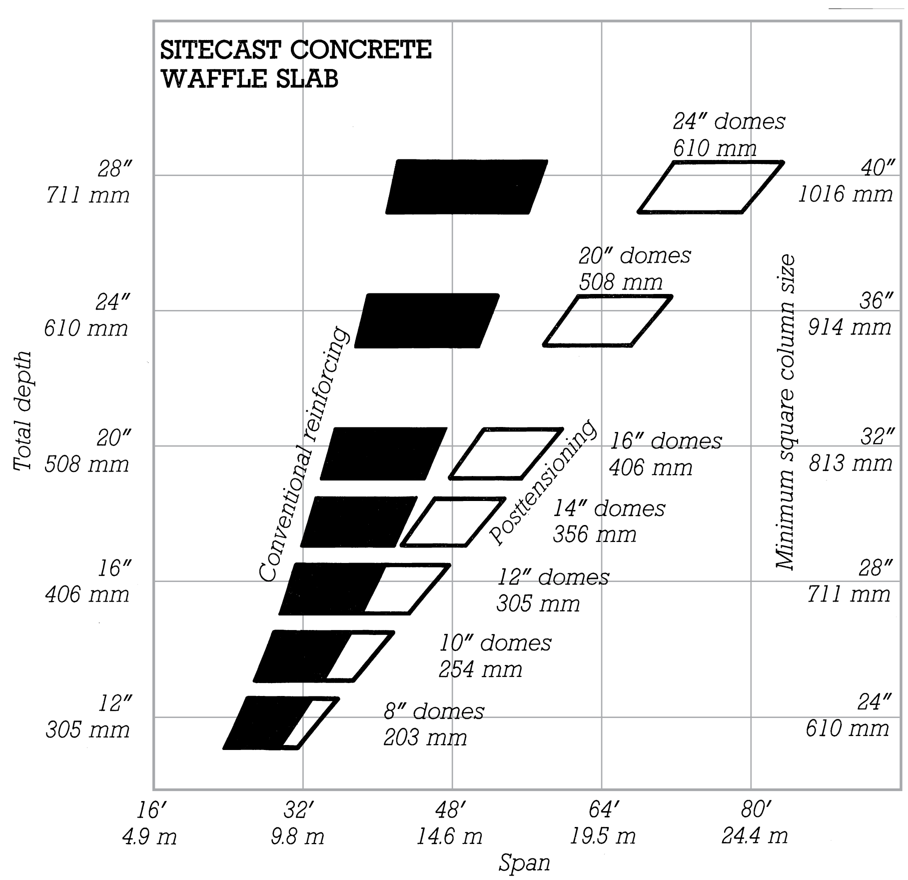
At waffle slab edges, the area between the outermost rib and the edge of the slab is filled solid to create an edge beam. Where the slab edge occurs over a line of columns, this edge beam runs column-to-column as a column strip. The slab may also cantilever beyond the columns by as much as one-third of a full span. In this case, both an edge beam and a solid strip running between the edge columns may be required.

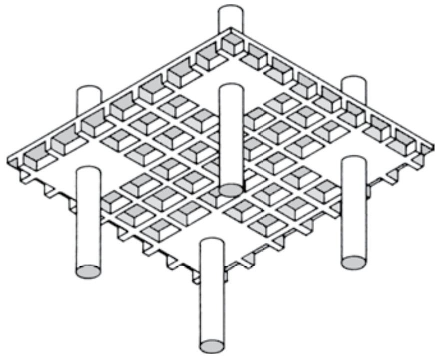
FIRE RESISTANCE AND WAFFLE SLAB CONSTRUCTION

Sitecast concrete waffle slabs may be used in both Combustible and Noncombustible Construction. Their fire resistance varies with the composition of the concrete and the placement of reinforcing. Use the following guidelines for preliminary design:

A 3-in. (76-mm) slab thickness between ribs gives a fire-resistance rating of 0 to 1 hour. A 3½-in. (89-mm) thickness gives a rating of 1 hour, a 4½-in. (114-mm) thickness gives a rating of 1½ hours, and a 5-in. (127-mm) thickness gives a rating of 2 hours. For higher fire-resistance ratings, the slab thickness may be increased further, fireproofing materials may be applied to the underside of the ribs and slab, or an appropriately fire-resistive ceiling may be used.

SITECAST CONCRETE WAFFLE SLAB





This chart is for concrete waffle slab construction, either conventionally reinforced or posttensioned. For light loads, read toward the right in the indicated areas. For heavy loads, read toward the left.

■ For rectangular bays, use the average of the spans of the two sides of the bay when reading from this chart.

■ Total depth is the sum of the depth of the ribs and the slab. (See the diagram on the facing page.) Depths are indicated on the chart for slabs from 3 to 4½ in. (76 to 114 mm) deep with standard pan sizes. The choice of the slab depth usually depends on the required fire-resistance rating for the system. See the facing page for fire-resistance information.

COLUMN SIZES AND LAYOUTS FOR WAFFLE SLAB CONSTRUCTION

In waffle slab construction, minimum column size is dependent on the overall thickness of the slab. The right-hand scale on the chart above provides minimum square column sizes for various slab thicknesses. For light loads, reduce the indicated column size by 2 to 4 in. (50 to 100 mm). For heavy loads, increase the indicated column size by 4 to 12 in. (100 to 300 mm).

For rectangular columns, use a column whose area is equal to that of the square column indicated. For round columns, use a column diameter one-third greater than the square column size indicated.

For columns in multistory buildings or for columns over 12 ft (3.7 m) tall, column size should also be checked using the charts on pages 110–111.

For maximum economy and efficiency of the two-way structural system, column layouts for waffle slab construction should adhere to the same guidelines as those described for flat plate construction. Column bays should be approximately square, and column offsets from regular lines should be minimized. See page 120 for a complete discussion of these guidelines.

PRECAST CONCRETE STRUCTURAL SYSTEMS

Compared to sitecast concrete, precast prestressed concrete framing systems are characterized by reduced depths and deflections for spanning members, faster construction, and increased quality and durability of the concrete itself. Where future changes to a structure are anticipated, precast concrete may have an advantage due to the relative ease with which individual elements in the system can be removed or replaced. The difficulty of fabricating rigid joints in precast concrete structures leads to a greater reliance on shear walls or cross bracing to achieve lateral stability than in sitecast concrete structures, and makes these structures potentially more sensitive to vibrations produced by heavy machinery or other sources. Precast concrete spanning elements are also often used in combination with other site-fabricated vertical loadbearing systems such as sitecast concrete, masonry, or steel.

SELECTING A PRECAST CONCRETE FRAMING SYSTEM

The initial choice of a framing system should be based on the desired spanning capacity or column spacing of the system and the magnitude of the expected loads on the structure. The following precast concrete systems are listed in order of increasing spans, load capacity, and cost:

- Solid flat slab
- Hollow-core slab
- Double tee
- Single tee

For short spans and light loads, select a system near the top of the list. For longer spans and heavier loads, systems toward the bottom of the list are required.

As with sitecast concrete, the inherent fire-resistive qualities of precast concrete construction allow these systems to remain wholly or partially exposed in the finished building. For this reason, the choice of a concrete framing system often has architectural implications that should be considered early in the design process. These include, for example, the absence of hollow spaces for the routing of concealed mechanical and electrical services, the possible use of the underside of the structural slab as a finish ceiling, and the aesthetic qualities of the system.

LAYING OUT A PRECAST CONCRETE SYSTEM

The economy of precast concrete construction depends on the repetition of standard elements and sizes. Use the following guidelines for preliminary layout of a precast concrete structure to ensure maximum economy:

- In the direction of the span of the deck members, use a modular dimension of 1 ft (0.3 m). If a wall panel has been selected, use the width of the panel as the modular dimension.
- In the direction transverse to the span of the deck members, use a module of 8 ft (2.4 m). If a deck member has been selected, use the width of that member as the modular dimension.
- Floor-to-floor heights need not be designed to any particular module, although the maximum repetition of the dimension chosen is desirable. Where precast wall panels are used, floor-to-floor heights should be coordinated with the height of the wall panel.
- Restrictions due to shipping and handling of members usually limit span lengths to 60 to 80 ft (18 to 24 m). Further transportation restrictions on depths of elements usually limit bay widths to between 24 and 40 ft (7 and 12 m) where girders are used.

In general, for maximum economy, any design features that require unique structural elements, variations in the sizes of elements, alterations in structural configuration, or deviation from the standard dimensions of the system should be avoided. Where the maximum flexibility of layout with precast concrete elements is desired, solid flat slabs or hollow-core slabs may be preferred over double or single tees for their shorter spans and the greater ease with which they may be sawn after casting, to conform to irregular conditions.

PROJECT SIZE

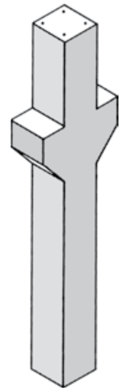
The economy of precast concrete construction increases with the size of the construction project. The following figures are approximate minimum quantities for which the production of precast concrete elements may be economical:

- 10,000 sq ft (1000 m^2) of architectural wall panels
- 15,000 sq ft (1500 m^2) of deck or slab members
- 1000 linear feet (300 m) of girders, columns, or pilings

PRECAST CONCRETE COLUMNS

Precast concrete columns are most commonly combined with precast beams in a post and beam configuration. Unlike sitecast concrete, with which rigid or semirigid joints between columns and beams are easily made, in precast concrete framing, such joints are more difficult to construct. For this reason, precast concrete framing systems most often rely on shear walls or braced framing for resistance to lateral forces.

Precast concrete columns are usually provided with conventional reinforcing. Prestressing may be used to reduce stresses on the columns during transportation and handling, or to improve a column's resistance to anticipated bending forces in service.



PRECAST CONCRETE COLUMN WITH TWO CORBELS

STANDARD SIZES AND SHAPES FOR PRECAST CONCRETE COLUMNS

Precast concrete columns are most commonly available in square profile in the sizes indicated on the charts on the facing page. Rectangular shapes can also be produced, although availability may vary with suppliers. For larger projects (requiring 1000 linear ft, or 300 m, or more of columns), economies of scale may make practical a greater range of sizes and configurations.

Columns up to approximately 60 ft (18 m) in length can be transported easily. Columns up to approximately 100 ft (30 m) in length may be shipped with special transportation arrangements.

For ease of casting, columns with corbels should be limited to corbels on two opposite sides or, at most, three sides.

Like all precast concrete elements, precast columns should be as consistent and regular as possible in dimensions and layout, in order to achieve maximum economy.

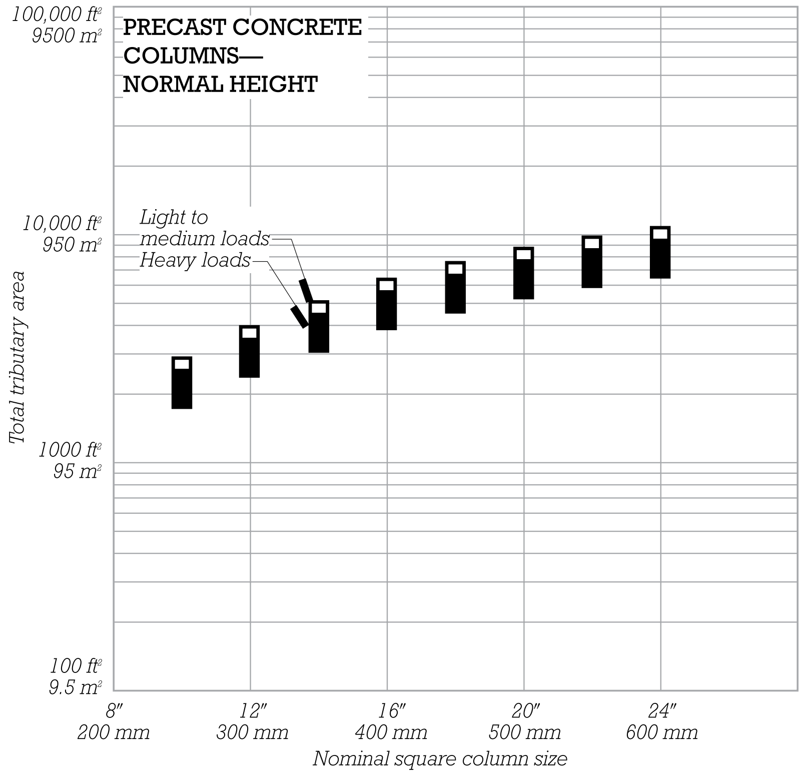
CONCRETE STRENGTH AND COLUMN SIZE

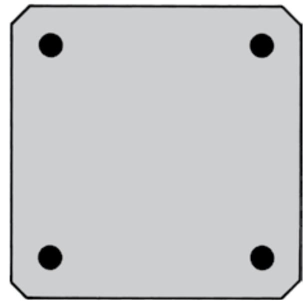
The top chart on the facing page is based on 5000 psi (35 MPa) concrete. Higher-strength concrete may also be used to reduce the required column size. To adjust the column sizes indicated in the top chart for variations in concrete strength, use the factors in the table to the right.

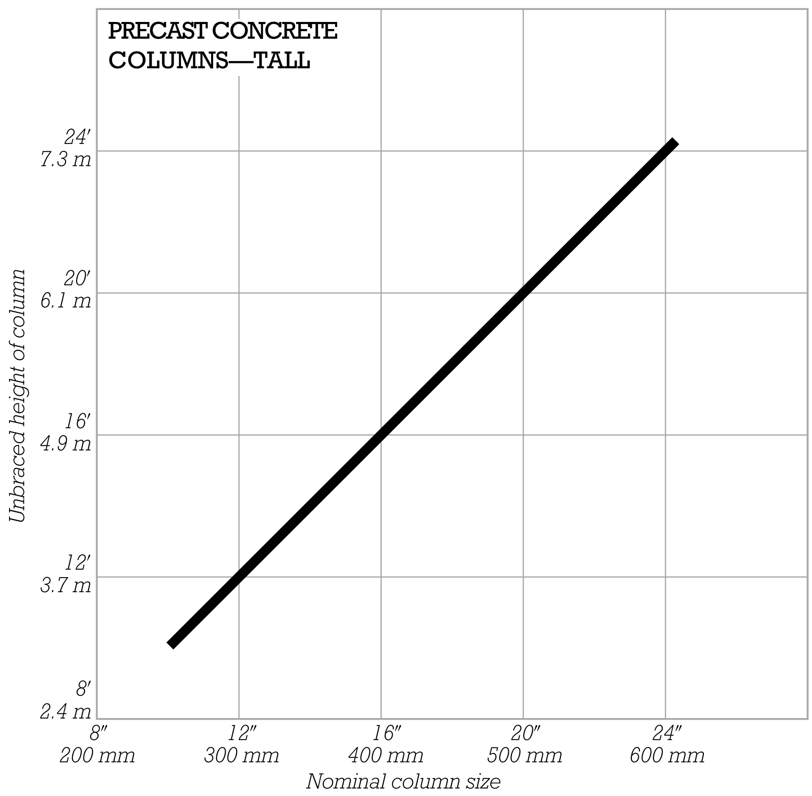
Concrete Strength		Multiply Column Size by:
6000 psi	(40MPa)	0.90
7000 psi	(50 MPa)	0.85
8000 psi	(55 MPa)	0.80
10,000 psi	(70 MPa)	0.70

FIRE RESISTANCE AND PRECAST CONCRETE COLUMNS

Precast concrete columns may be used in both Combustible and Noncombustible Construction. Their fire resistance varies with the composition of the concrete and the placement of reinforcing. For preliminary design, you may assume that a 2-hour fire-resistance rating can be achieved with columns not less than 10 in. (250 mm) on a side. Fire-resistance ratings of 3 and 4 hours can be achieved with columns 12 in. (300 mm) and 14 in. (350 mm) in the minimum dimension, respectively.







The top chart is for precast concrete columns up to 12 ft (3.7 m) tall between floors. For light to medium loads, read in the upper open areas of each bar. For high loads, read in the lower solid areas. *Total tributary area* is the summed area of the roof and all floors supported by the column.

■ For rectangular columns, select a column of area equal to the square size indicated.

■ Actual column size is equal to nominal size.

For columns taller than 12 ft (3.7 m), read from both charts on this page, using the larger size indicated by either one. *Unbraced height of column* is the vertical distance between floors or other supports that brace the column laterally against buckling.

■ For rectangular columns, read the chart's nominal column size, using the least dimension of the column.

PRECAST CONCRETE WALL PANELS

There is great variety in precast concrete wall panel types for applications ranging from single-family residential buildings to tall commercial structures. Panels may be prestressed or conventionally reinforced; they may be loadbearing or nonbearing; they may or may not contribute to the lateral stability of a building; they may be flat, ribbed, or more intricately shaped; and they may be solid, hollow, or a sandwich of concrete with an insulating core. Precast concrete wall panels may be used in conjunction with a precast concrete framing system or with other framing systems, such as steel or concrete.

PANEL TYPES

Flat panels may be one to two stories high. Ribbed panels may be up to four stories high.

Wall panels may also be formed in a great variety of unique shapes. The design of such panels depends on knowledge of precasting methods. When the use of such panels is planned, the necessary consultants or suppliers should be sought out early in the design process. For the preliminary sizing of such panels, use the chart for ribbed panels on the facing page. Such loadbearing wall panels may be used in buildings up to approximately 16 to 20 stories in height.

Panels with openings usually are not prestressed. Panels without openings may be prestressed to reduce thickness or to limit stresses in the panels during transportation and handling.

SIZES OF PRECAST CONCRETE WALL PANELS

Solid panels are commonly available in thicknesses of 3½ to 10 in. (89 to 254 mm). Sandwich or hollow-core panels range in thickness from 5½ to 12 in. (140 to 305 mm). Ribbed wall panels are commonly available in thicknesses of 12 to 24 in. (305 to 610 mm).

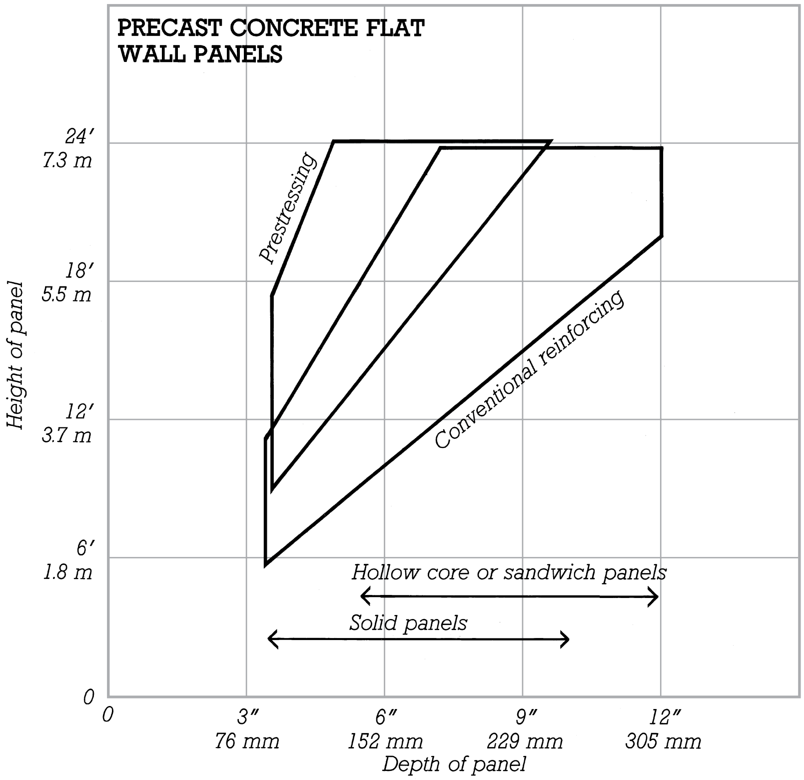
For preliminary design, assume an 8-ft (2.4-m) width for all panel types. With special provisions, panels in widths of up to approximately 14 ft (4.3 m) may be transported without excessive economic penalty.

FIRE RESISTANCE AND PRECAST CONCRETE WALL PANELS

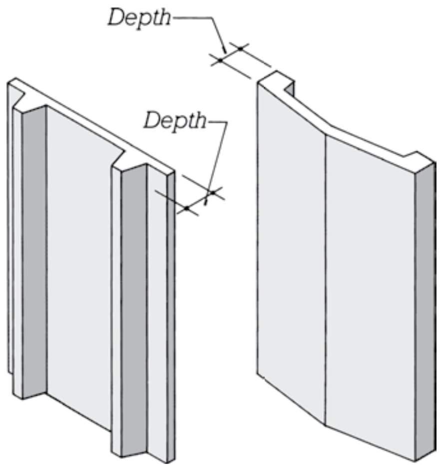
Precast concrete wall panels may be used in both Combustible and Noncombustible Construction. Their fire resistance varies with the composition of the concrete and the type and placement of reinforcing. In sandwich panels, core insulation influences fire resistance as well. The following guidelines may be used for preliminary design:

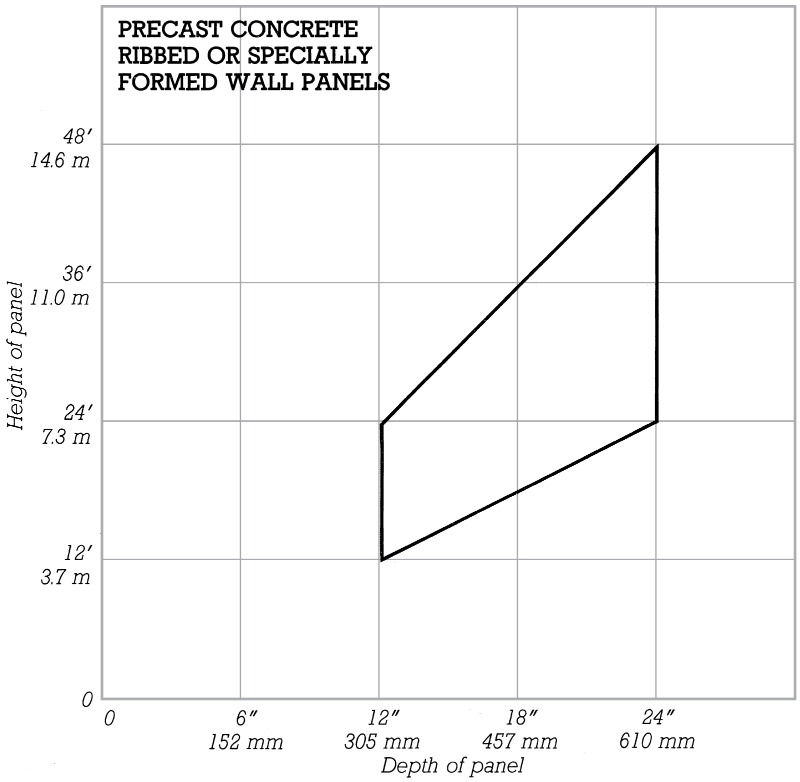
Panels must be at least 6.5 in. (165 mm) thick to achieve a fire-resistance rating of 4 hours. A 3-hour rating is achieved at a thickness of 6 in. (152 mm), a 2-hour rating at 5 in. (127 mm), and a 1-hour rating at 3.5 in. (89 mm).

PRECAST CONCRETE WALL PANELS



The top chart is for flat precast concrete wall panels, either prestressed or conventionally reinforced. For nonbearing panels, read toward the left in the indicated areas. For loadbearing panels, read toward the right.





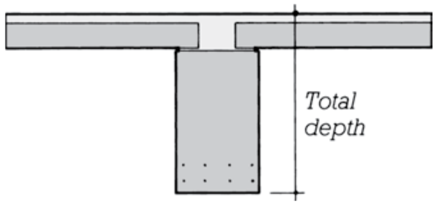
The bottom chart is for precast concrete wall panels formed with ribs, stems, or other stiffening features. For nonbearing or prestressed panels, read toward the left in the indicated area. For loadbearing panels, conventionally reinforced panels, or panels with integral window openings, read toward the right.

■ *Depth of panel* is the total depth of the panel and any stiffening features.

■ For the preliminary design of spandrel panels, use the distance between columns for the height indicated on either chart.

PRECAST CONCRETE BEAMS AND GIRDERS

Precast prestressed concrete girders are commonly used to carry all varieties of precast concrete decking elements between columns or bearing walls. They can be used in any building type where precast concrete construction is to be considered.

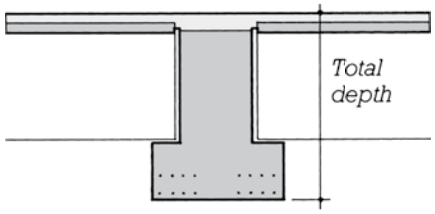


RECTANGULAR BEAM WITH SOLID OR HOLLOW-CORE SLABS

TOTAL DEPTH OF FLOOR SYSTEMS

Rectangular beams are commonly used with solid or hollow-core slabs resting on top of the beam. Total floor depth at the beam is the sum of the depths of the slab, the topping if any, and the beam.

Inverted T- and L-beams are commonly used with double and single tees. When they are erected, the top of the tees should be level with or slightly above the top of the beam. When the tees rest directly on the beam ledge, the total floor depth at the beam is the depth of the tee, the topping if any, and the depth of the ledge. Deeper tees may have their ends notched or "dapped" so as to rest lower on the beam. The use of dapped tees may result in total floor depths of as little as the depth of the tee itself plus any topping.

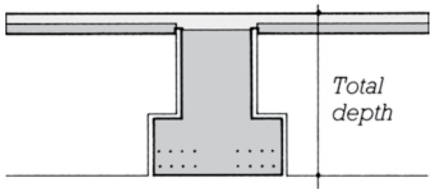


INVERTED T-BEAM WITH SINGLE OR DOUBLE TEES

FIRE RESISTANCE AND PRECAST BEAMS AND GIRDERS

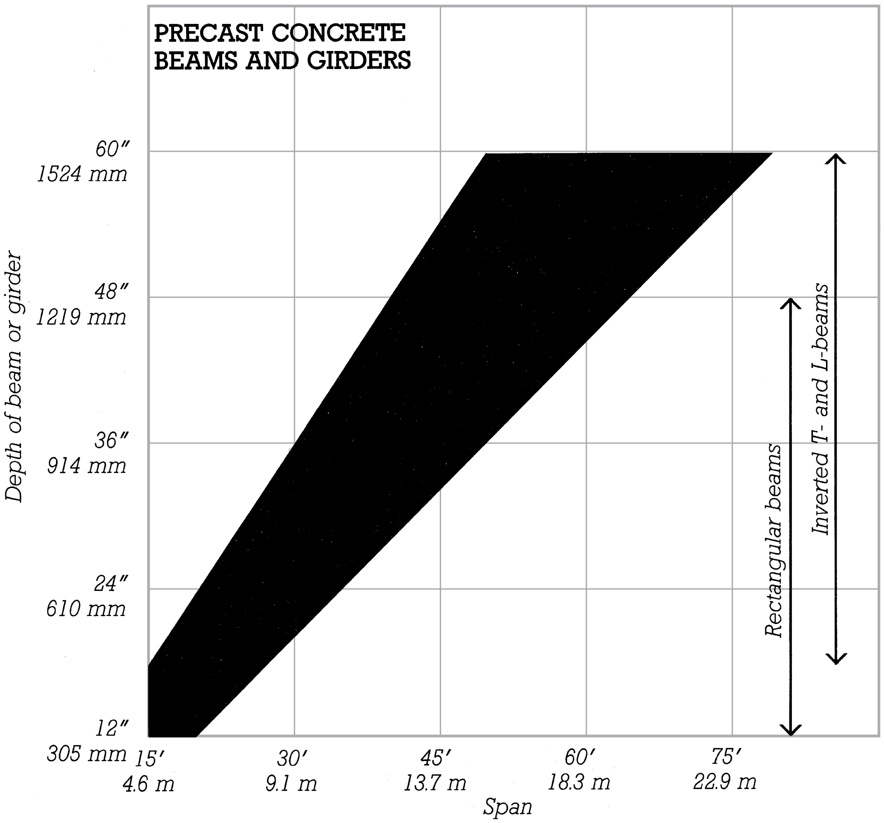
Precast concrete beams and girders can be used in both Combustible and Noncombustible Construction. Their fire resistance varies with the composition of the concrete and the placement of reinforcing. The following guidelines may be used for preliminary design:

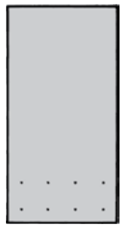
A prestressed concrete beam that is not smaller than 9.5 in. (241 mm) in width has a fire-resistance rating of 3 hours. For a 2-hour rating, the minimum width is 7 in. (178 mm), and for 1 hour it is 4 in. (102 mm).



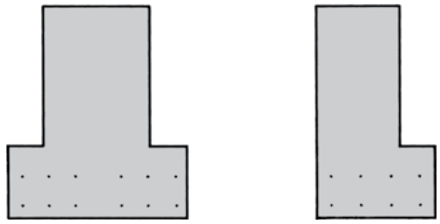
INVERTED T-BEAM WITH DAPPED TEES

PRECAST CONCRETE BEAMS AND GIRDERS





RECTANGULAR BEAM



INVERTED T- AND L-BEAMS

This chart is for precast concrete beams and girders. For light loads or close beam spacings, read toward the right in the indicated area. For heavy loads and large beam spacings, or for girders, read toward the left.

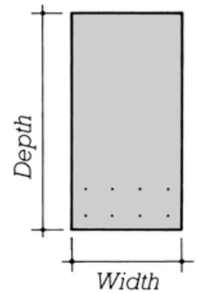
COMMON SIZES OF PRECAST CONCRETE BEAMS AND GIRDERS

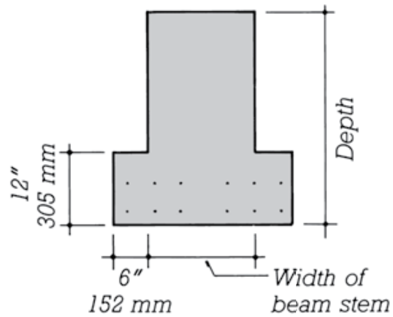
Rectangular beams commonly range in depth from 18 to 48 in. (450 to 1200 mm). Widths range from 12 to 36 in. (300 to 900 mm).

Inverted T- and L-beams commonly range in depth from 18 to 60 in. (450 to 1500 mm), although sections deeper than 48 in. (1200 mm) may be subject to shipping or handling restrictions. Widths of the beam stem (not including the ledges) range from 12 to 30 in. (300 to 750 mm).

Standard dimensions for beam ledges are 6 in. (150 mm) wide and 12 in. (300 mm) deep.

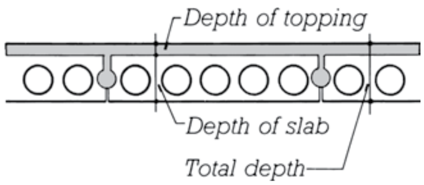
Beam sizes typically vary in increments of 2 or 4 in. (50 or 100 mm). Availability of sizes varies with suppliers.





PRECAST CONCRETE SLABS

Precast prestressed concrete solid and hollow-core slabs are commonly used in hotels, multifamily dwellings, commercial structures, hospitals, schools, and parking structures. Lighter-weight slab systems also find use in residential building construction.



HOLLOW-CORE SLABS WITH SITECAST TOPPING

CONCRETE TOPPING ON PRECAST SLABS

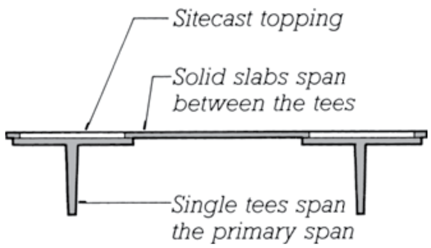
Sitecast concrete topping is often applied over precast concrete slabs to increase the structural capacity of the slab, increase the fire resistance of the floor system, allow the integration of electrical and communications services into the floor, or provide a more level and smoother floor surface in preparation for subsequent finishes. In buildings such as hotels, housing, and some parking structures, where these requirements may not exist, the use of untopped slabs may be an acceptable and economical system choice.

SPECIAL SYSTEMS

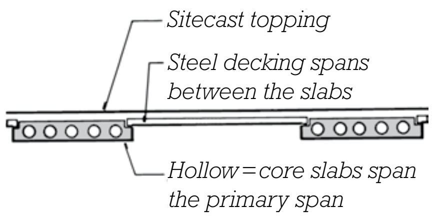
Both solid and hollow-core slabs may be combined with other spanning elements to create several types of hybrid floor structures referred to as *spread systems*. These systems can provide increased economy and may allow greater flexibility in the choice of building module.

- Either slab type may be used as a secondary element spanning transversely between longer-spanning single tees, double tees, or channels.

- Hollow-core slabs can be spread from 2 to 3 ft (0.6 to 0.9 m), with corrugated steel decking spanning between the slabs. This system is usually topped. Where many floor penetrations are expected, this is an attractive system due to the relative ease of creating openings through the steel decking.



SPREAD TEE SYSTEM WITH SOLID SLABS



HOLLOW-CORE SLAB SPREAD SYSTEM

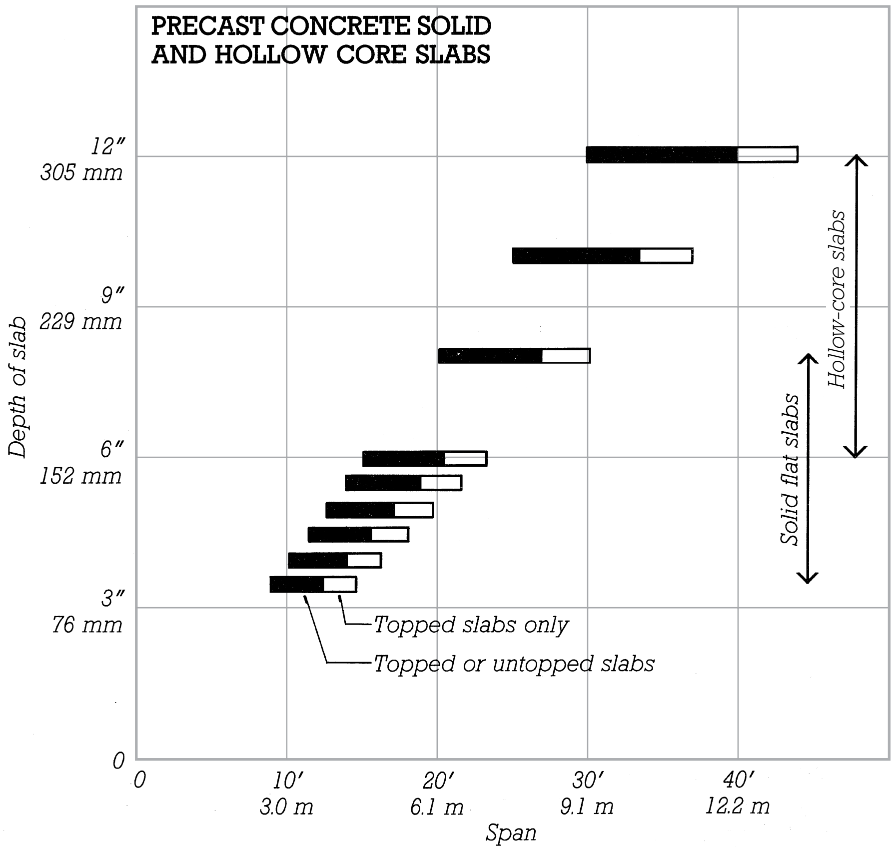
FIRE RESISTANCE AND SOLID FLAT SLABS AND HOLLOW-CORE SLABS

Precast concrete slabs can be used in both Combustible and Noncombustible Construction. Their fire resistance varies with the composition of the concrete and the placement of reinforcing. Use the following guidelines for preliminary design:

Solid slab floors must be at least 5.5 in. (140 mm) thick to have a fire resistance rating of 3 hours. For a 2-hour rating, the required thickness is 4.5 in. (115 mm). A 1½-hour rating requires a minimum thickness of 4 in. (100 mm), and a 1-hour rating requires a thickness of 3.5 in. (90 mm). These thicknesses include the depth of any topping.

Hollow-core slabs at least 8 in. (200 mm) deep achieve a fire-resistance rating of 2 hours without a concrete topping. With the addition of a 2-in. (50-mm) topping, the rating rises to 3 hours.

PRECAST CONCRETE SLABS



SOLID SLAB

HOLLOW-CORE SLAB

This chart is for precast concrete solid flat slabs and hollow-core slabs. For light loads, read toward the right in the indicated areas. For heavy loads, read toward the left.

■ The open areas indicated on the chart are for slabs with an added sitecast concrete topping only. The solid areas are for either topped or untopped slabs. The depths indicated on the chart are for the slabs alone, without any additional topping. Where a topping is used, add 2 in. (50 mm) to the indicated depths for preliminary design. See the facing page for further information on the use of concrete toppings.

COMMON SIZES OF SOLID AND HOLLOW CORE SLABS

Solid flat slabs come in depths of 3½ to 8 in. (90 to 200 mm). For depths of 6 in. (150 mm) and above, however, hollow-core slabs are usually more economical. Typical widths are 8 to 12 ft (2.4 to 3.7 m).

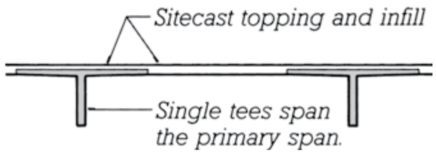
Hollow-core slabs come in depths of 6 to 12 in. (150 to 300 mm). Typical widths are 2 ft, 3 ft 4 in., 4 ft, and 8 ft (0.6, 1.0, 1.2, and 2.4 m). Availability of sizes varies with suppliers.

PRECAST CONCRETE SINGLE AND DOUBLE TEES

Precast prestressed single and double tees can span farther than precast slabs and are commonly used in building types such as commercial structures, schools, and parking garages.

SPREAD TEE SYSTEMS

Single and double tees may be combined with other spanning elements to create hybrid framing systems referred to as *spread systems*. In these systems, the tees are erected with spaces between them. These gaps are then bridged with precast solid or hollow-core slabs, or with sitecast concrete that is poured as part of the topping. These systems can increase the economy of long-span structures and may allow greater flexibility in the choice of building module.



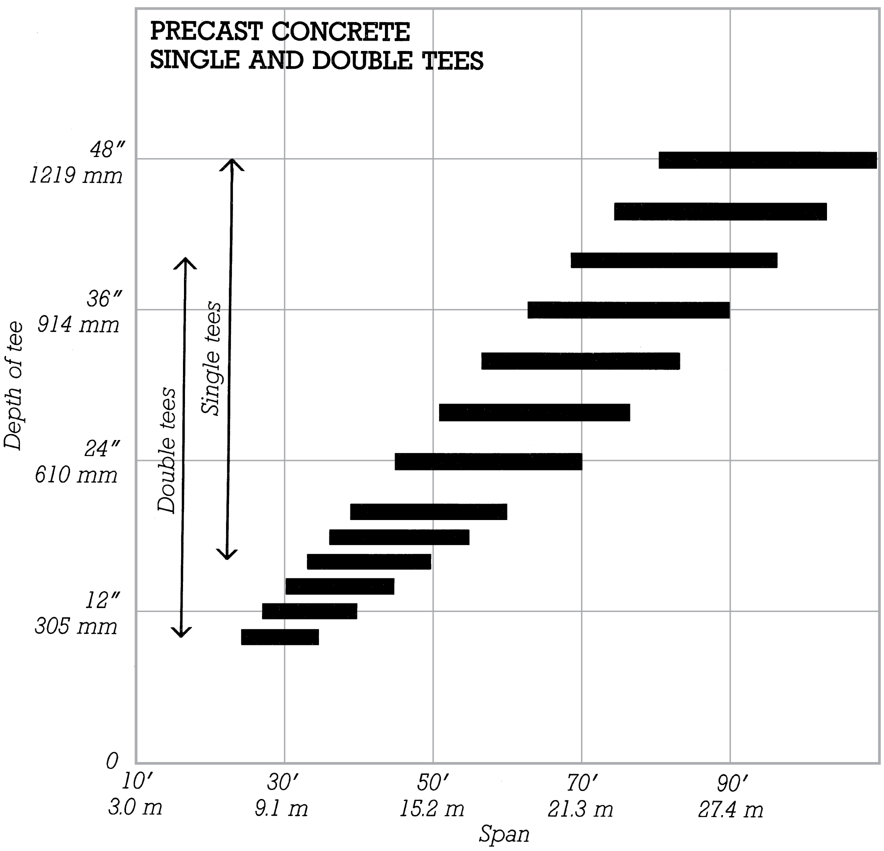
SPREAD TEE SYSTEM WITH SITECAST CONCRETE TOPPING AND INFILL

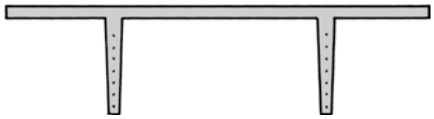
FIRE RESISTANCE AND SINGLE AND DOUBLE TEES

Precast concrete single and double tees may be used in both Combustible and Noncombustible Construction. Their fire resistance varies with the composition of the concrete in the slabs and topping, and with the placement of reinforcing. Use the following guidelines for preliminary design:

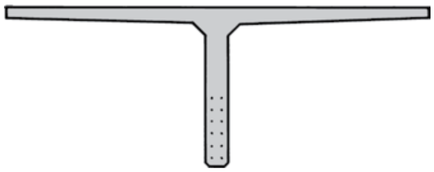
For a fire-resistance rating of 3 hours, single and double tees require applied fire-protection materials or an appropriately fire-resistive ceiling. For ratings of 2 hours and less, protection may be achieved by regulating the thickness of the concrete topping: 3.5 in. (90 mm) for 2 hours, 3.0 in. (75 mm) for 1½ hours, and 2.0 in. (50 mm) for 1 hour.

PRECAST CONCRETE SINGLE AND DOUBLE TEES





DOUBLE TEE



SINGLE TEE

This chart is for precast concrete single and double tees. For light loads, read toward the right in the indicated areas. For heavy loads, read toward the left.

■ Because they do not require temporary support against tipping, double tees are faster and more economical to erect than single tees. Their use is preferred wherever possible.

Double tees are most commonly used with a concrete topping. For preliminary purposes, add 2 in. (50 mm) to the depths indicated on the chart. Roof slabs and deep single tees may not need to be topped.

COMMON SIZES OF PRECAST SINGLE AND DOUBLE TEES

Double tees come in widths of 4, 8, 10, and 12 ft (1.2, 2.4, 3.0, and 3.7 m). Common depths are 10 to 40 in. (250 to 1000 mm). Single tees come in widths of 6, 8, 10, and 12 ft (1.8, 2.4, 3.0, and 3.7 m). Common depths are 16 to 48 in. (400 to 1200 mm). Tees longer than 60 to 80 ft (18 to 24 m) may be less economical because of increased transportation and handling costs. Availability of sizes varies with suppliers.

SECTION

3

DESIGNING WITH DAYLIGHT

1 DESIGN CRITERIA FOR DAYLIGHTING SYSTEMS

This chapter will help you evaluate the suitability of daylight illumination to your project and, if you choose to proceed with daylighting design, to select appropriate daylighting strategies.

Daylighting is the use of natural light to illuminate the interior of a building. Daylight can provide high-quality, color-balanced lighting. It can reduce a building's energy consumption, contribute to the conservation of natural resources and the protection of the environment, improve the aesthetic quality of the workplace, provide a psychological connection to nature and the outdoors, and increase business productivity. There are many factors that influence the potential for daylighting design on a project. Location, climate, building form, program, and the perceived value of daylighting by the building's owners and its occupants can all play a role. When buildings are designed for daylight illumination, the architectural impact is significant. Massing, orientation, structural configuration, layout of interior elements and spaces, and choice of materials may all be influenced by daylighting considerations. For these reasons, daylighting should be addressed at the earliest stages of design, when the opportunities for successfully incorporating effective strategies into a project are greatest. The information in the following pages will help you evaluate the potential of daylighting for your project, and, if you choose to pursue this option, provide preliminary design guidelines for developing a building that effectively utilizes natural daylight for illumination.

A high-quality luminous environment requires adequate levels of illumination; it requires light that is well distributed to prevent excessive contrast, brightness, and glare; and it requires light that is reliably available. Sources of daylight include both the sun and the surrounding, clear or clouded, luminous sky. Direct sunlight is too intense to be allowed to fall directly on tasks or within the visual field. It must be diffused, reflected, or moderated in some way. Furthermore, direct sunlight is not necessarily the most reliable source of daylight. The sun's position in the sky changes constantly, causing the quality of its light to vary with orientation, time of day, and season. At any time, the sun may be obscured by cloud cover, geographic features, or nearby man-made structures. For these reasons, the simplest way to incorporate daylighting into most projects is to rely on indirect sky light as the primary source of illumination and, where sunlight is present, to ensure that it does not directly intrude into the task area. This is the daylighting approach emphasized in the following pages.

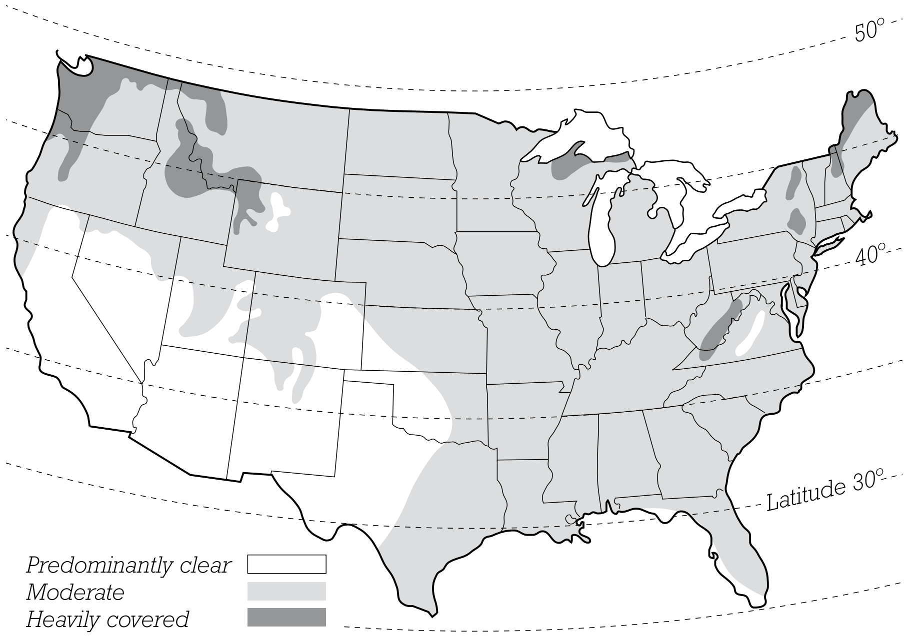
Designs utilizing direct sunlight as the primary source of illumination are also feasible, particularly in areas with prevailing clear skies. The information provided here is relevant to such projects as well.

SKY COVER

The map on this page indicates average clear and covered (cloudy) sky conditions within the continental United States. Conditions are characterized as *predominantly clear*, *moderate*, or *heavily covered*, corresponding to an average annual sky cover of less than 50%, from 50% to 70%, or greater than 70%, respectively. Only in areas indicated as predominantly clear—mainly the Southwest and parts of Florida—are clear skies prevalent on average more than half of all daylight hours. In the remaining areas—most of the continental United States—covered or partially covered sky conditions predominate more than half of the time. Although not shown on this map, the heavily populated regions of Canada are within moderately or heavily covered areas as well.

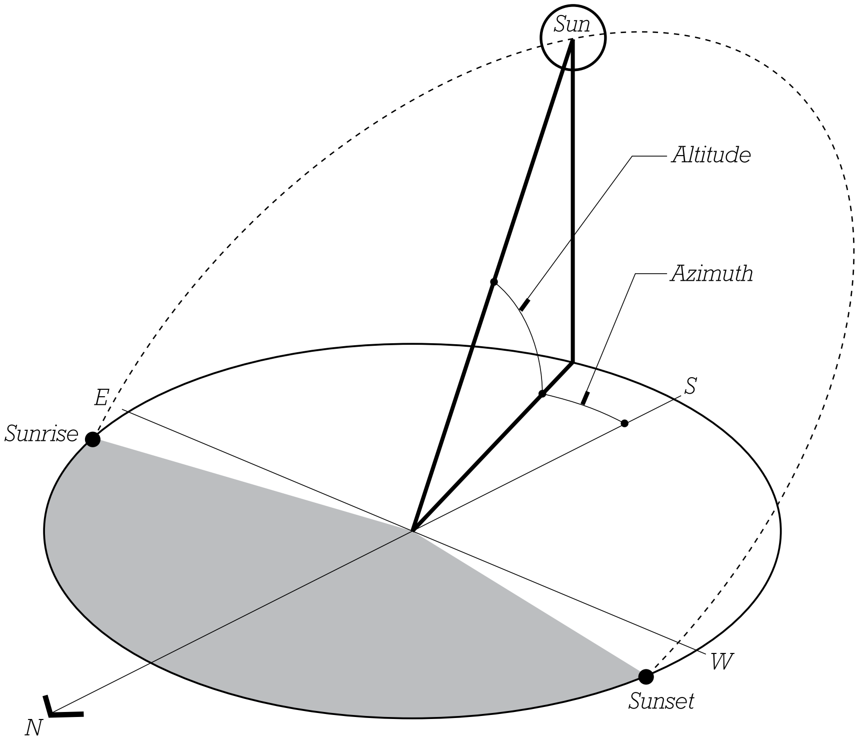
You can use this sky cover information when reading from charts later in this daylighting section (pages 155, 157). For example, in predominantly clear areas, levels of available daylight are consistently highest. When reading from these charts to find the required area for windows or toplighting, you can read low in the recommended ranges because of the high levels of available daylight. When reading from the charts for projects located within moderate sky cover areas, read near the middle of the recommended ranges. And when reading from the charts for projects located in heavily covered areas, read high in the recommended ranges. Because local sky conditions vary from regional averages, the information presented here should be supplemented with local data wherever possible.

Regardless of sky cover conditions, control of direct sunlight is always an important consideration. To prevent unacceptable levels of glare and contrast, sunlight should always be prevented from falling directly within the visual field of task areas.



SKY COVER CONDITIONS

The sun moves over and around a building during the course of each day. Successful daylighting design requires that the building occupants receive acceptable levels of consistent, high-quality illumination throughout this cycle. The chart below provides information about the path of the sun for various latitudes and different times of the year, information that is important in understanding the impact of the sun on a building. To find the approximate latitude for a project located in the continental United States, use the latitude indications on the Sky Cover Conditions map on the previous page. For other locations, consult comparable sources of information. As an example, Savannah, Georgia, lies approximately at 32° north latitude. At the summer solstice, June 21, the sun rises at an azimuth of 115° (measured from the south axis), and at solar noon it reaches an altitude of 81° (measured from the horizon). The length of the day from sunrise to sunset is approximately 14 hours.



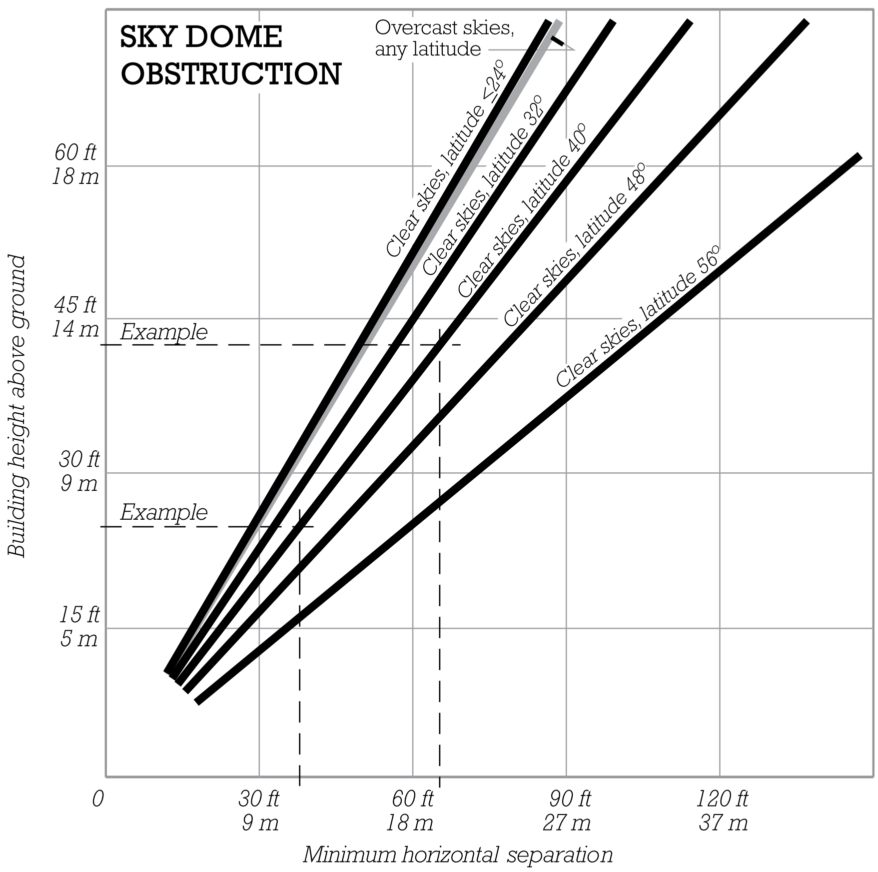
THE PATH OF THE SUN

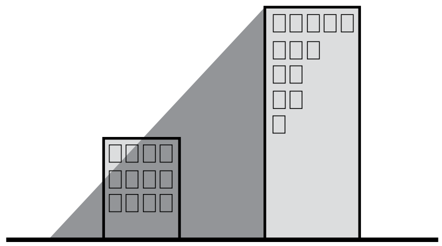
The path of the sun also varies over the course of the year, the magnitude of this variation increasing with greater distance from the equator. For example, at 24° north latitude, from summer solstice to winter solstice, the length of the day varies by 4 hours and the sun's rising or setting position moves on the horizon 47°. In comparison, at 52° north latitude, the length of the day varies by 8 hours, and the sun's rising or setting position moves 120°. Also note that at 24° north latitude, at the winter solstice, the sun rises to 42° above the horizon at noon. At 52° north latitude, it rises only 16° above the horizon at its highest point.

Use the information in this table to chart the approximate path of the sun around your building. As you continue on the following pages, this information will help you to determine a favorable building orientation and opening configuration for maximizing daylight access and limiting exposure to unwanted direct sunlight. In particular, pay special attention to times of the day and year when the sun is low in the sky. These times present the most difficult problems for sunlight control. Building orientation, configuration of daylight openings, and the anticipated hours of building occupancy should all be considered relative to these low-angle sun conditions.

Latitude	Hours of Daylight (sunrise to sunset)	Altitude of Noon Sun	Azimuth of Rising or Setting Sun
24° North			
Summer Solstice	14	90°	115°
Winter Solstice	10	42°	68°
32° North			
Summer Solstice	14	81°	115°
Winter Solstice	10	36°	62°
40° North			
Summer Solstice	14	74°	120°
Winter Solstice	9	28°	60°
48° North			
Summer Solstice	15	66°	125°
Winter Solstice	8	20°	55°
52° North			
Summer Solstice	16	62°	130°
Winter Solstice	8	16°	50°

SKY DOME OBSTRUCTION





Daylighting design requires a building to have line-of-sight access to sufficient sky area for adequate daylight exposure. The preceding chart can be used in two ways: first, to determine the extent to which surrounding structures may obstruct your building's access to daylight, and second, to determine the extent to which your building obstructs surrounding structures' access to daylight.

For example, assume a project location at 40° north latitude, with clear sky conditions, a neighboring building 24 ft (7 m) tall, and a planned height of 42 ft (13 m) for your building. To ensure that your building has full access to daylight, read the chart using the adjacent building's height of 24 ft (7 m) to determine that there should be at least 37 ft (11 m) between the two structures. To ensure that the adjacent building's daylight is not obstructed by your project, read the chart using your building's height of 42 ft (13 m) to determine that there should be at least 65 ft (20 m) between the two structures. To protect access to daylight for both buildings, use the larger of the two answers, in this case, 65 ft (20 m).

This chart is for determining daylight obstruction between buildings.

- To ensure full access to daylight for your building, read the chart using the height of adjacent buildings or structures. Locate your building so that it is at least as far away from each of these structures as indicated on the chart.
- To ensure that your building does not obstruct access to daylight for adjacent structures, read the chart using the height of your building and locate your building at least as far away from the adjacent structures as indicated.
- For buildings located in predominantly covered sky areas at any latitude, read the chart along the sloped line for overcast skies. For buildings located in predominantly clear sky areas, read the chart along the sloped line for the latitude of the project or interpolate between lines for other latitudes. For buildings located in moderate sky cover areas, read along the line for overcast skies to find the optimum building separation under worst-case conditions, or read along the appropriate line for clear skies to determine building separation under more favorable clear sky conditions. (For more information on determining sky cover conditions and the latitude of a project, see pages 143, 144.)

BUILDING SITING AND SHAPE

Daylighting design is intimately related to building form. This section provides guidelines for the siting, massing, and internal configuration of a building to provide the greatest opportunities for successful daylighting.

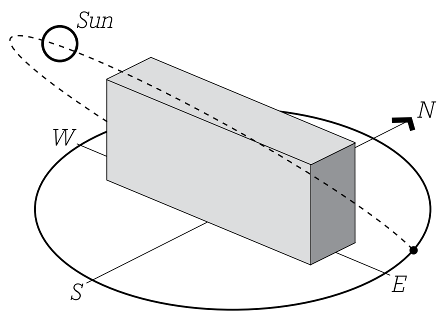
BUILDING SIZE

Strategies for daylighting differ with building size. For small buildings, the ratio of exterior skin area to enclosed volume is relatively large. This means that for residences and other small-scale buildings, generally the designer has ample opportunities to locate occupied areas in close proximity to daylight sources such as windows and rooftop openings. In small buildings, the main challenge for the designer is to control the quality of the daylight, distributing it effectively and avoiding excessive contrast or brightness.

On the other hand, in large buildings, the ratio of exterior envelope area to enclosed volume may be much less, and providing adequate levels of daylight to interior areas becomes a design challenge with greater formal implications. In large buildings, both building shape and interior configuration become critical to a successful daylighting scheme.

ORIENTATION

Daylight openings should be oriented to allow the control of direct sunlight while providing access to sources of daylight that are consistent in quality and provide high levels of illumination. In the Northern Hemisphere, these conditions are best met in a south orientation, where, for the largest part of the day, the sun remains high in the sky, and the surrounding sky provides high levels of manageable daylight. A northern exposure is also favorable, providing consistent daylight, although at illumination levels lower than those from a southern exposure. The most difficult orientations for daylight openings are toward those portions of the sky in which the sun is low in its daily path, generally toward the east and west, although precise orientation varies with location and time of year. These exposures should be avoided or, if used, studied carefully, as the quality of the daylight is highly variable and the control of direct sunlight is problematic. Thus, buildings elongated in the east–west direction, and plan configurations that otherwise maximize exposure to the north and south sky while shielding exposure to the east and west, will generally provide the most favorable daylighting opportunities. In some cases, strategically located adjacent structures may also play a role in shielding a building from unfavorable exposure to the sun when it is low in the sky.

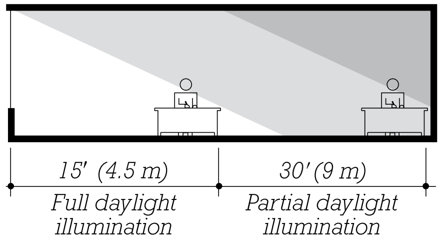


BUILDING ORIENTATION

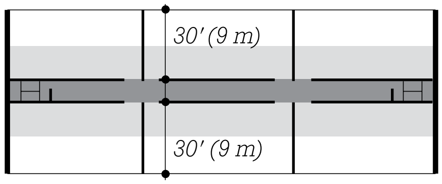
BUILDING SHAPE

In multistory buildings, daylight is provided through windows in exterior walls. Daylighting such as this is termed *sidelighting*, and its effectiveness is limited by the depth to which it can penetrate horizontally into the building's interior. For example, in a typical office building, daylighting can provide full illumination to task areas no farther than 12 to 15 ft (3.5 to 4.5 m) from exterior wall openings and can provide partial illumination to areas no farther than 24 to 30 ft (7.5 to 9 m) from the exterior. Thus, to maximize effective daylighting in a commercial office building, work areas should be located, to the greatest extent possible, no more than 30 ft (9 m) from exterior walls with daylight access. Consider, for example, a double-loaded corridor plan. Total building depth in the north–south direction should not exceed approximately 70 ft (21 m), allowing 30 ft (9 m) for work areas on either side of a 10-ft (3-m)-wide central corridor. In general, narrow or elongated plans, L- or U-shaped plans, and courtyard or atrium buildings provide greater access to daylight than more compact arrangements.

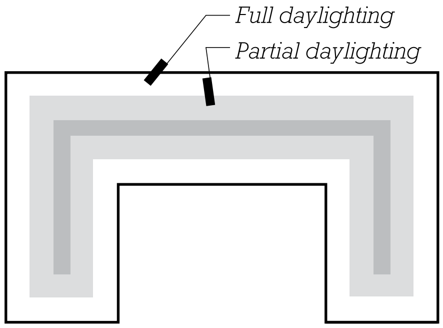
Where occupied areas occur directly below roofs, daylighting may also be provided through overhead skylights or other types of roof openings, devices collectively referred to as *toplighting*. Large single-story buildings, such as factories or warehouses, are well suited to toplighting configurations. Opportunities for toplighting can be increased with building sections that step or are otherwise configured to create increased roof area. Considering sidelighting and toplighting together, daylighting design generally benefits from elongated or articulated building massing that increases the building perimeter and thereby increases opportunities for daylight access to the interior.



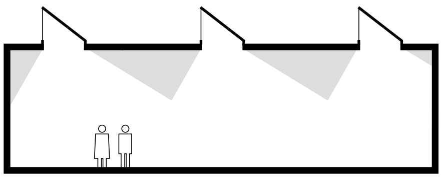
SIDELIGHTING



DOUBLE-LOADED CORRIDOR



ELONGATED BUILDING PLANS



TOPLIGHTING

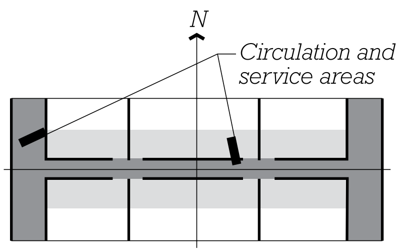
BUILDING DESIGN DEVELOPMENT

As a design progresses and the building configuration continues to develop, the impact of daylighting should be investigated in more detail and with more attention to local conditions. For example, a building not oriented on the cardinal points of the compass may interact with early morning and late afternoon sun in ways that require more detailed investigation. Local topography and weather patterns may affect access to daylight at various times of the day or year. Adjacent structures may reflect light or obscure the sky in ways that positively or negatively affect a project. Patterns of use within a building may also favor certain orientations or times of day. For example, an elementary school building in which classrooms are unoccupied after 3 P.M. may be more tolerant of a western exposure than a commercial office space habitually occupied until later in the day. As the project design develops, more detailed analysis, daylighting modeling, and the advice of daylighting experts should all be used.

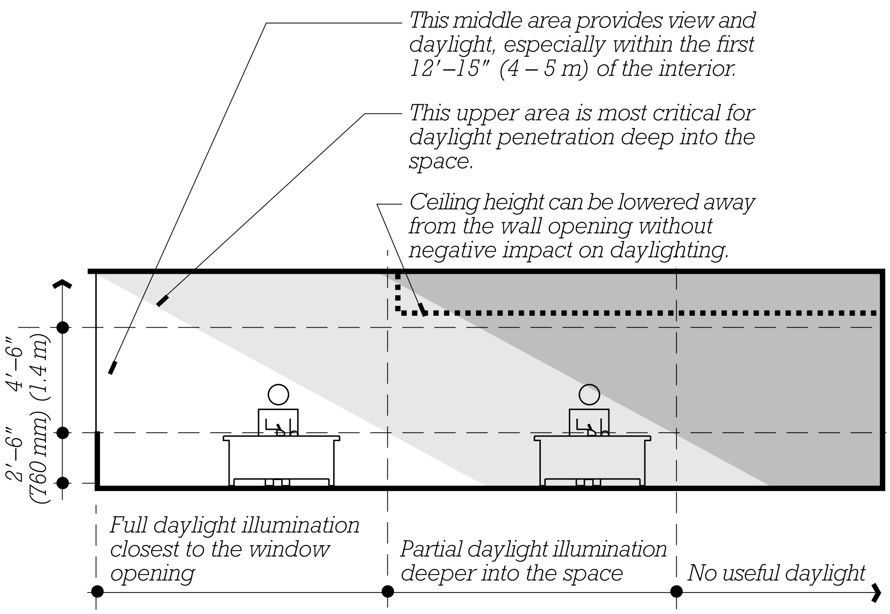
Not all activities within a building can benefit equally from daylighting. Consideration of the lighting needs of the various components of the building program can help guide decisions regarding where each component may be located. For example, vertical circulation, bathrooms, and storage areas gain little or no benefit from daylighting and can be located in portions of the floor plate that daylight cannot reach. Or such functions can be grouped on the east and west ends of a building, helping to shield other interior areas from these problematic exposures.

A critical factor in daylighting design is the treatment of ceiling height, especially close to the exterior. Considering the section diagram on this page, the exterior wall can be divided into three distinct zones. The portion of the wall below 30 in. (760 mm), roughly the level of a typical work surface, makes no significant contribution to daylighting. Openings in the middle portion of the wall, up to approximately 7 ft (2.1 m), provide daylighting in areas closest to the opening and offer exterior views. To maximize the effectiveness of daylight illumination deeper in the space, the window opening must extend above 7 ft (2.1 m), necessitating a ceiling as high as possible and the avoidance of spandrel beams or other elements close to the perimeter that can obscure this portion of the wall opening. This criterion places significant constraints on the planning of structural and mechanical building systems, such as the location of deep beams or HVAC ductwork, and must be considered in the earliest stages of design if it is to be achieved. (For more detailed information about window opening height and daylight horizontal penetration, see pages 153–155.)

Considering areas intended to benefit from daylight illumination, they must have direct line of sight access to a source of daylight, such as a window or skylight, or even a large, light-colored surface reflecting daylight from such a source. Partitions, structural elements, mechanical and electrical system components, furnishings, and other elements that extend above the lower third of the space should be arranged to minimize their potential to obstruct daylight sources. See page 154 for more information about configuring interior elements for optimal daylighting.



SHIELDING EAST AND WEST EXPOSURES



DAYLIGHT ZONES AND THE WINDOW WALL

(Thanks to Joel Loveland, University of Washington Department of Architecture and Seattle Lighting Design Lab, for the concept of this diagram.)

SMALL BUILDINGS

Small building energy consumption tends to be driven primarily by heating and cooling loads associated with thermal exchange through the building's exterior skin. Thus, in cold climates, energy use is dominated by the need to replace heat lost through the walls and roof during the cold months. In warmer regions, energy consumption may be driven by the removal of heat gained through the exterior enclosure during the warm months. Daylighting design can contribute to the reduction of energy consumption in both of these circumstances.

In cold climates, south-facing sidelighting can provide daylight illumination as well as solar heat gain for energy savings. Where direct sun is admitted into the structure as a source of heat, internal shading, diffusing, or reflecting strategies should be used to protect visual task areas from excessive brightness or contrast. To control heat gain during warmer months, external overhangs or other shading devices can be used to exclude direct sun from the interior during these periods. For more information on solar heating strategies for small and medium-sized buildings, see pages 228–230.

Daylight illumination can also contribute to reduced cooling loads in warm climates. Indirect light from the north sky or from well-shaded southern exposures is an excellent source of illumination with low heat content. Direct sunlight can be reflected off exterior surfaces before it is admitted into a structure, thereby leaving a significant portion of its heat content outside the building. And, as explained in more detail in the next section, even direct sunlight can be an energy-efficient source of illumination when it is properly controlled and efficiently distributed within the interior.

LARGE BUILDINGS

In larger buildings, energy consumption is increasingly dominated by internally generated heat loads, rather than by heat exchange through the building skin. The removal of heat generated by occupants, lighting, and equipment is often the most significant factor in the overall energy performance of a large commercial building.

In conditions such as these, daylighting can contribute significantly to energy savings. Natural daylight illumination is free. Wherever daylighting can replace an electric light source, electric energy consumption is reduced directly. In addition, because well-designed daylight illumination generates less heat than most sources of artificial illumination, daylighting can lessen a building's internal heat load, further reducing energy consumption. The following chart tabulates the *efficacy* of daylight and various types of electric lighting—that is, the amount of useful light in relation to the heat produced (measured in lumens per watt). The higher the efficacy, the more energy efficient is the light source. Note that daylighting is one of the highest efficacy sources.

For daylight to achieve its potential for high efficacy, it must be well utilized within the building. Direct sunlight that causes excessive heat gain, or daylighting that in other ways creates an unsatisfactory visual environment, will not reduce the use of electric light or save energy. However, when well designed and implemented, natural daylighting offers significant opportunities for savings in large building energy consumption.

Light Source Efficacy, Measured in Lumens/Watt (Higher values indicate higher efficiency)	
Natural daylighting	70–130
Light-emitting diode	75–130
Fluorescent	45–105
Metal halide	45–100
Tungsten halogen	15–35
Incandescent	5–20

2 CONFIGURING AND SIZING DAYLIGHTING SYSTEMS

This chapter will help you lay out the components of a daylighting system and estimate the size of daylight openings to provide the required levels of interior illumination for a project.

Different tasks require different levels of illumination. The nature of a task, the need for accuracy and efficiency, and the visual acuity of the occupants are all contributing factors. For example, navigating the lobby of a commercial office building requires minimal attention to detail and is not a task with unusual demands for speed or accuracy. Consequently, relatively low ambient lighting levels are acceptable. On the other hand, an accountant, much of whose day is spent reading and transcribing densely formatted, low-contrast financial statements and ledgers, and whose efficiency and accuracy of work are critical, should be provided with much higher levels of task illumination. Follow the steps below to determine recommended lighting levels for a project and to estimate the size and quantity of daylight sources for your building.

General Space Illumination	
Category A—Public spaces, dark spaces	Nighttime corridors and lobbies, waiting rooms, bedrooms
Category B—Simple orientation	Dance halls, dining halls, transportation terminal concourses, residential living spaces
Category C—Occasional visual tasks	Daytime corridors and lobbies, reception areas, auditoriums, banks, worship spaces
Task Illumination	
Category D—Visual tasks of high contrast or large size	Conference rooms, office work with high-contrast tasks, factory simple assembly, residential kitchens
Category E—Visual tasks of medium contrast or small size	Drafting of high-contrast work, classrooms, offices, clerical tasks, factory work of low contrast or moderately difficult assembly
Category F—Visual tasks of low contrast or very small size	Drafting of low-contrast work, laboratories, factory work with difficult assembly

Step 1: Choose a Lighting Level Category

From the chart on this page, choose a lighting level by selecting the category that most closely matches the activity that takes place in the given space.

Step 2: Adjust Your Choice

Each lighting level category represents a range of illumination levels suitable for the tasks described. On some of the charts on the following pages, each category is shown as a band representing the range of values. When reading from these charts, you may read higher or lower in the appropriate band, depending on the following factors:

Higher light levels are recommended in areas with occupants primarily of age 55 years or older, in areas with predominantly dark, nonreflective surroundings or task backgrounds, and in areas where tasks are carried out that require an unusually high degree of speed and accuracy. If two or more of these factors apply, read *high* in the lighting level category bands in the following charts. Conversely, lower light levels are recommended in areas with occupants primarily under the age of 40, in areas with light-colored, highly reflective surroundings or task backgrounds, and in areas where tasks are carried out that do not demand unusual speed or accuracy. If two or more of these factors apply, read *low* in the lighting level category bands in the following charts.

AMBIENT SPACE AND TASK ILLUMINATION

The table on this page lists recommended lighting levels for both general space illumination and task illumination, with task illumination requiring higher light levels because of the greater visual demands associated with these activities. For projects for which full reliance on daylighting is not achievable or desired, a strategy that may be considered is to provide ambient space illumination with daylighting and supplement this with electric lighting for task illumination. For example, where a typical office space may require Category E task illumination levels at the worker's desk, Category C illumination levels should be adequate for movement around these areas. In this case, daylighting design can be based on Category C illumination levels and task lighting at the desk can be provided from artificial sources.

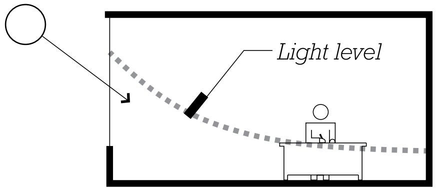
SIDELIGHTING

Sidelighting through windows and clerestories is the predominant means of providing daylight illumination in most buildings.

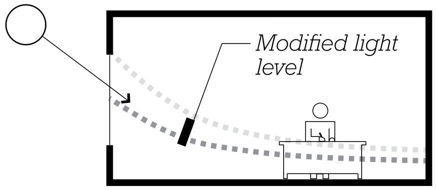
The intensity of sidelighting is highest near the opening and diminishes with increasing distance from the opening. The depth to which sidelighting can provide illumination within a building is largely dependent on the height of the opening. Under typical conditions, sidelighting can provide effective illumination for depths up to approximately 2½ times the height of the opening above the plane of the work surface. For example, in an office with 9-ft (2.7-m)-high windows and 30-in. (760-mm)-high desks, the top of the window is 6½ ft (2.0 m) above the work plane, and daylight should be able to provide full illumination up to a depth of approximately 16 ft (5 m) (6.5 ft × 2.5 = 16.25 ft). For more detailed information on the depth of sidelighting penetration for various illumination levels and opening heights, see pages 154–155.

In designing with sidelighting, attention must be given to maximizing its reach deep into the structure, as well as minimizing excessive brightness close to the wall openings. A variety of techniques are possible. *Light shelves* create more evenly distributed illumination levels throughout a space. Although light shelves may reflect some light deeper into the interior, their primary benefit comes from reducing brightness levels close to the window. By reducing the highest illumination levels, more uniform lighting is achieved overall, giving the impression of an improved lighting environment. Light shelves can also prevent direct sunlight from falling directly within the work area.

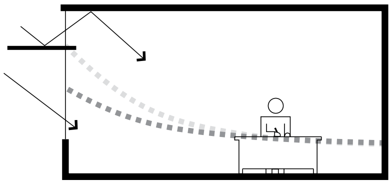
Exterior overhangs may be solid or louvered. Extending a solid overhang beyond the building wall is essentially the same as increasing the depth of the room, and illumination is reduced comparably. If light levels are adequate, this can be an effective way to block direct sun as well as reduce excessive brightness close to the window. Louvered overhangs, if designed with attention to prevailing sun angles, can block direct sunlight selectively while admitting indirect light.



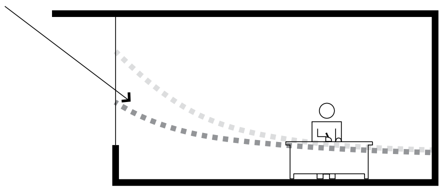
SIDELIGHTING



REDUCED WINDOW HEAD HEIGHT



LIGHT SHELF

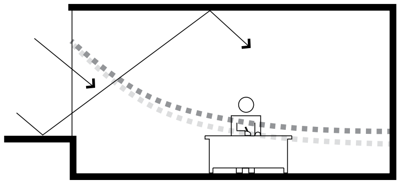


EXTERIOR OVERHANG

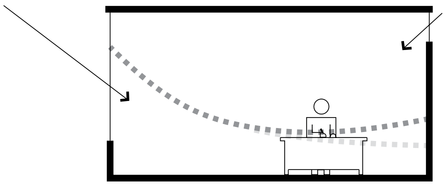
Reflective sills can increase the depth to which light penetrates within the space. However, care must be taken to avoid creating excessive glare for occupants close to the opening.

Secondary sources of daylight that are located at some distance from a primary wall opening, such as rear windows or skylights, can be used to increase light levels deep within a space, thereby creating more uniform lighting, as well as reducing strong shadowing and contrast.

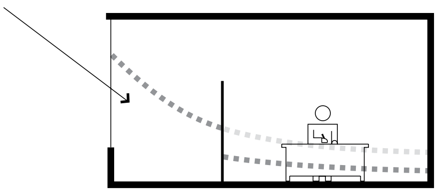
Obstructions to daylight within the space should be avoided. Wherever possible, elements that can block daylight, particularly those high up in the space, should be located as far from wall openings as possible. Where a plan includes both open plan areas and enclosed space, the open plan areas should be placed closest to the wall openings and the enclosed spaces should be located so as to minimize the obstruction of daylight. Where enclosed spaces must be located close to wall openings, consider transparent or translucent enclosing materials to allow daylight to penetrate beyond these areas. Opaque elements, such as partitions or ceiling beams, can assist in daylight distribution when oriented perpendicular to wall openings. Particularly when such elements are light-colored and located close to such openings, they can both reflect daylight more deeply into the space and reduce contrast levels close to the opening.



REFLECTIVE SILL



SECONDARY DAYLIGHT SOURCE



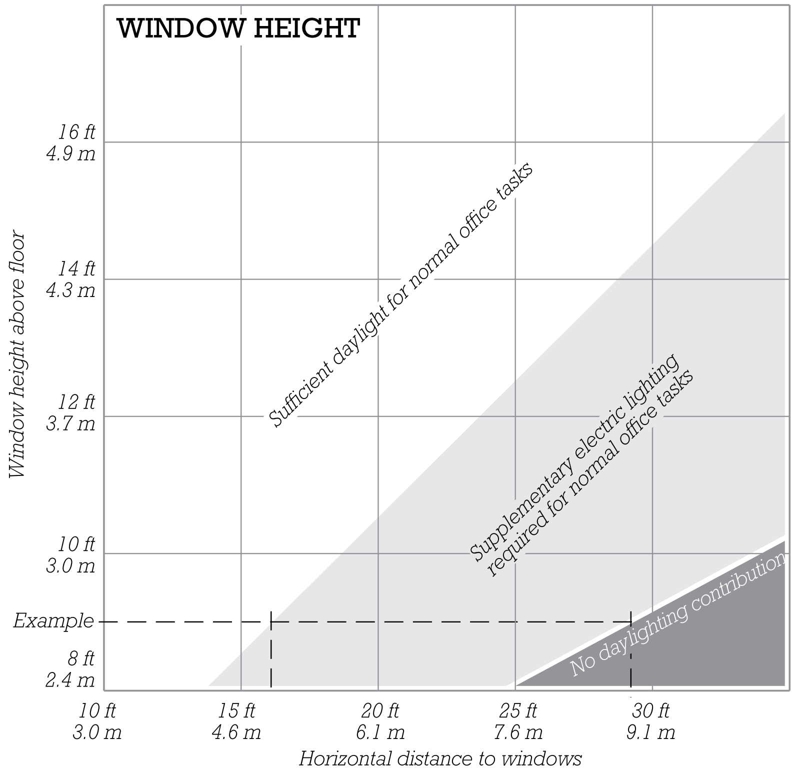
DAYLIGHT OBSTRUCTIONS

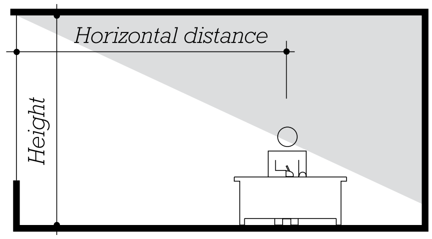
SIZING SIDELIGHTING

Use the charts on the opposite page to estimate the required size of wall openings for natural daylighting. Both charts assume that window bottoms are no higher than 30 in. (760 mm) above the floor, window glazing is clear, and walls and ceilings are white or light-colored. If these conditions are not met, daylighting effectiveness will be reduced.

For example, reading the top chart, a window extending 9 ft (2.7 m) above the floor will provide full daylighting for normal office tasks up to a horizontal distance of approximately 16 ft (4.9 m) from the window. Daylighting supplemented with electric lighting can be provided up to 29 ft (8.8 m) away.

As a second example, reading the bottom chart, a 6000-sq-ft (560-m^2) business office area is to be illuminated with daylight from adjacent windows. Using the table on page 152, we select Category E, visual tasks of medium contrast and size, as the appropriate lighting level. Reading the chart, we determine that 6000 sq ft (560 m^2) of floor area requires between 1000 and 2000 sq ft (93 and 186 m^2) of window area for full daylighting. Or, if electric task lighting is to be provided, general area illumination meeting Category C criteria can be provided with windows 200 to 400 sq ft (19 to 37 m^2) in area. (This scenario is not illustrated on the chart.)



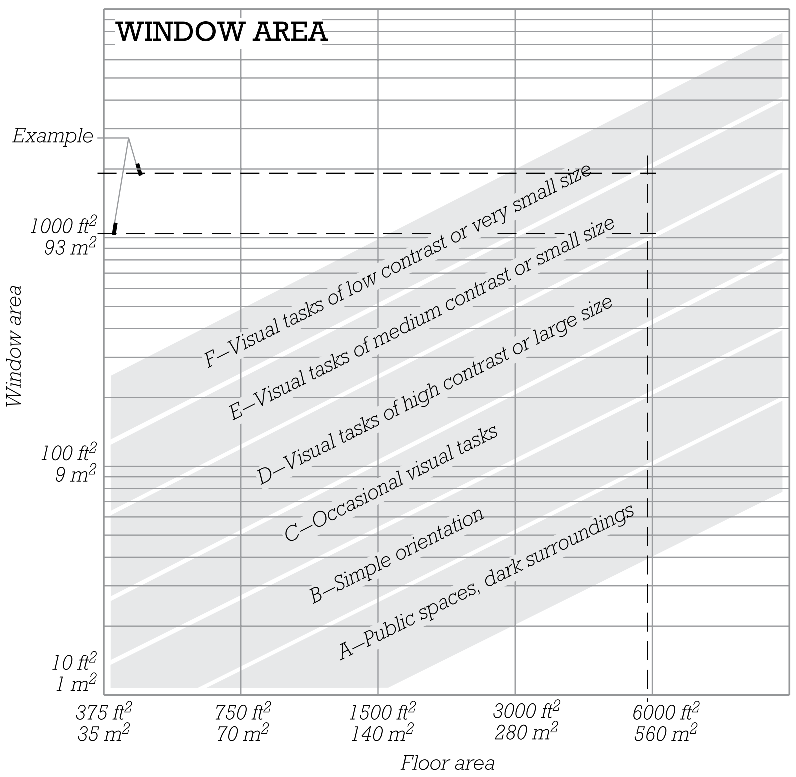


Use the top chart to determine the minimum wall opening height for adequate horizontal daylight penetration for normal office tasks.

■ To ensure even light distribution throughout a space, window openings should be at least half as wide as the length of the wall in which they are located.

Use the bottom chart to determine the total wall opening area necessary for full daylighting of various tasks occupying a given floor area. To determine the most appropriate illumination category for the space under consideration, see page 152. For floor areas larger than those tabulated on the chart, read the chart using a smaller area and then multiply the result proportionally.

■ For buildings in predominantly clear sky areas, read low in the ranges indicated on the chart. For buildings in heavily covered sky areas, read high in the indicated ranges. See page 143 to determine the sky cover conditions for your project's location.



TOPLIGHTING

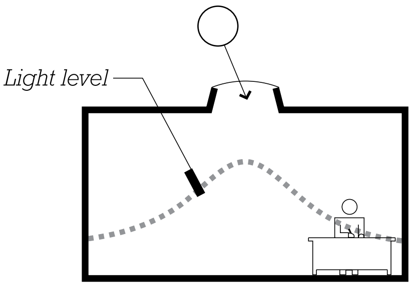
Toplighting is most commonly exploited as a daylighting strategy in large single-story structures.

Toplighting can be provided either by *skylights*, with horizontal or low-sloped glazing, or by *roof monitors*, with vertical or steeply sloped glazing. Because of variation in the brightness of the sky from horizon to directly overhead, illumination levels from skylights are roughly three times greater than those associated with sidelit windows of the same opening area. Illumination is highest directly below a skylight opening and diminishes with increasing horizontal distance. With roof monitors, which admit daylight from the side, highest illumination levels tend to be offset to the side opposite the monitor glazing. The intensity of illumination from roof monitors varies with their orientation. In the Northern Hemisphere, south-facing monitors provide illumination levels approximately equal to those of skylights of the same glazing area. Monitors facing other directions provide approximately one-half the illumination of a skylight of the same area.

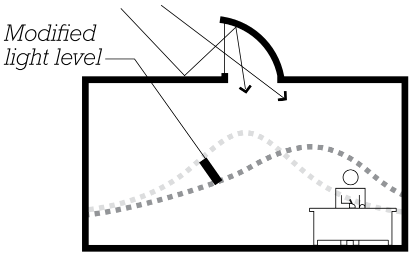
Spaced toplighting with multiple sources can minimize extremes in illumination levels. Sources of toplighting should be spaced no more than one to two times the height of the openings above the floor in order to provide acceptably uniform levels of illumination within the space.

In predominantly overcast areas, toplighting with clear glazing and no other means of sunlight control may be acceptable. In most areas, toplighting should be oriented away from the sun, or control devices should be used to prevent sunlight from passing unimpeded to the task area. *Interior reflectors*, exterior louvers, translucent light-diffusing materials, and deep openings with reflective sides can all be effective in this regard. When these devices are placed on the interior, they may also be helpful in distributing daylight farther from the opening and creating more even illumination within the space. Devices located exterior to the opening can exclude solar heat from the interior and may be helpful in areas where high heat gain is particularly a concern.

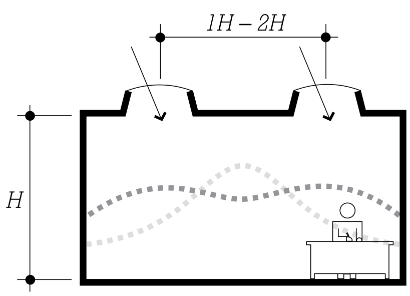
Combined sidelighting and toplighting can be used to distribute daylighting deeper into the interior than is possible with sidelighting alone. To avoid excessive variation in illumination levels, spacing of daylight sources should not exceed the recommendations in the adjacent diagram.



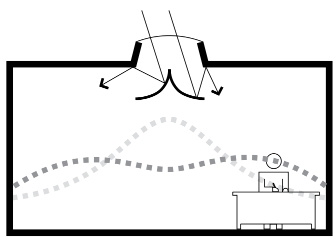
SKYLIGHT



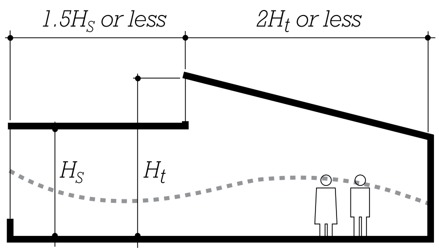
ROOF MONITOR



SPACED TOPLIGHTING



INTERIOR REFLECTORS



COMBINED SIDELIGHTING AND TOPLIGHTING

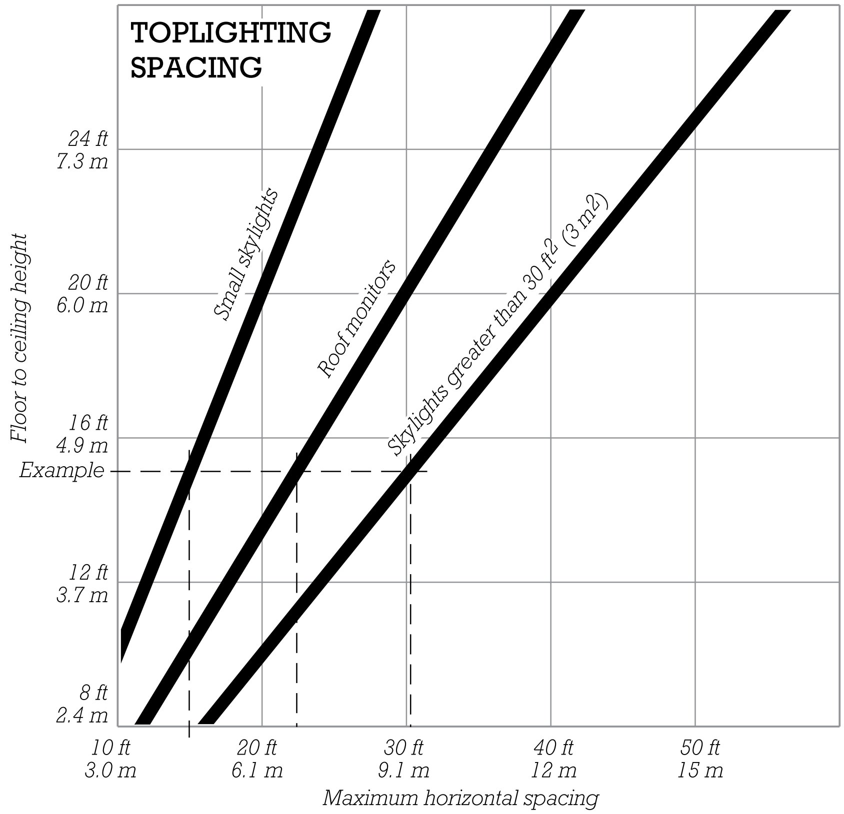
SIZING TOPLIGHTING

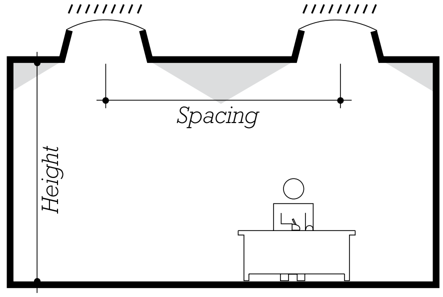
Use the charts on the facing page to estimate the required area of roof openings for natural daylighting.

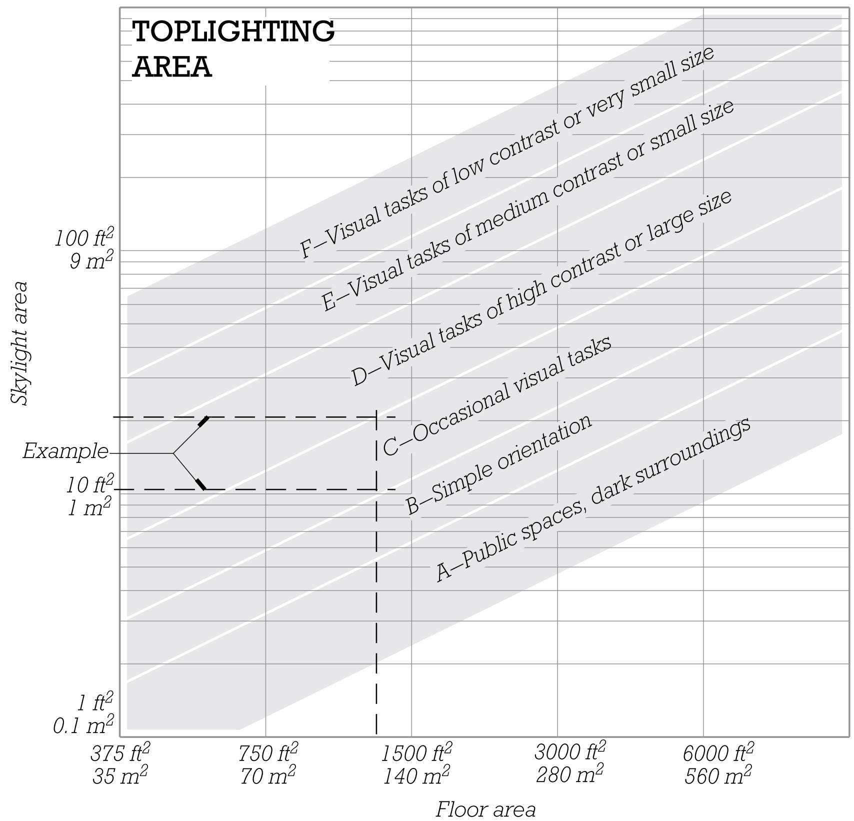
For example, reading the top chart, with a floor-to-ceiling height of 15 ft (4.5 m), small skylights should be spaced horizontally no more than 15 ft (4.5 m) center-to-center, roof monitors should be spaced no more than 22 ft (7 m), and large skylights should be spaced no more than 30 ft (9 m).

As a second example, reading the bottom chart, a 1000-sq-ft (93-m^2) hotel lobby area is to be illuminated with north-facing roof monitors. Using the table on page 152, we select Category C, simple orientation, as the appropriate lighting level. Reading the chart, we determine that 1000 sq ft (93 m^2) of floor area requires between 10 and 20 sq ft (0.9 and 1.9 m^2) of skylight area for full daylighting. Doubling the result for a north-facing monitor, our final answer is 20 to 40 sq ft (1.9 to 3.7 m^2) of glass area.

TOPLIGHTING







Use the top chart to determine maximum horizontal spacing for skylights and roof monitors so as to maintain acceptably even lighting levels throughout a space.

Use the bottom chart to determine the skylight or roof monitor opening area necessary for daylighting various tasks over a given floor area. To determine the most appropriate illumination category for the space under consideration, see the table on page 152. For floor areas larger than those tabulated on the chart, read the chart using a smaller area and then multiply the result proportionally.

■ For skylights and south-facing roof monitors, read directly from the chart. For roof monitors facing other than south, use twice the indicated area.

■ For buildings in predominantly clear sky areas, read low in the ranges indicated on the chart. For buildings in heavily covered sky areas, read high in the indicated ranges. See page 143 to determine sky cover conditions for the project's location.

SECTION

4

DESIGNING SPACES FOR MECHANICAL AND ELECTRICAL SERVICES

1 SELECTING HEATING AND COOLING SYSTEMS FOR LARGE BUILDINGS

This chapter will help you select a heating and cooling system for the preliminary design of a large building.

THE ENVIRONMENTAL IMPACTS OF HEATING AND COOLING BUILDINGS

In North America, the energy used to heat and cool buildings accounts for roughly 15% of this region's total energy consumption from all sectors and uses (residential and commercial buildings, industry, and transportation). As such, building heating and cooling systems, on their own, are major energy consumers and potentially significant contributors to environmental harm and climate change.

Guidance on selecting heating and cooling systems for large and small buildings, based on many criteria, can be found in this and following sections of the book. Given the magnitude of the environmental risks now facing our planet, the design of such systems should always include consideration of strategies for reducing energy consumption. For example:

■ Give preference to heating and cooling systems that operate most efficiently.

■ Consider systems that reduce reliance on nonrenewable fossil fuels—coal, petroleum, and natural gas—which, when consumed, are major contributors to climate change.

■ Integrate energy-saving strategies such as energy recovery (page 175), energy storage (page 190), geothermal exchange (page 183), and passive systems (pages 221–238) into heating and cooling designs where possible.

■ Design to high-performance building standards such as green building certifications, net-zero energy, passive house, or others.

ZONING A BUILDING FOR HEATING AND COOLING

Before attempting to select a heating and cooling system, rough out a zoning scheme for the building, establishing areas that differ from one another in their thermal conditioning requirements and will be controlled separately. Sometimes a zone should be no larger than a single room (a classroom, a hotel room). Sometimes a number of spaces with similar requirements can be grouped into a single zone (a group of offices that are occupied during the day, but not at night; a group of galleries in a museum). Sometimes rooms must be put in separate zones because they have differing requirements for air quality or temperature (locker rooms in a gymnasium complex, cast dressing rooms in a theater). Sometimes different zones must be established to deal effectively with different rates of internal generation of heat (a kitchen in a restaurant or dining hall, a computer room in a school, a metal-casting area in an industrial building).

Perimeter floor areas are frequently zoned separately from interior spaces, accounting for the solar heat gains and exterior wall heat losses that occur in these areas. Where solar heat gains are high, the perimeter may be zoned separately for each orientation of the window wall, to account for heat gains occurring at different times of the day or during different seasons of the year. In commercial buildings where each tenant will be billed separately for heating and cooling costs, each tenant space will constitute a separate zone. A large business or mercantile building might be divided into several large zones of approximately equal size, to fit the capacities of the fans and ductwork or the capacities of packaged systems. A multiuse building may incorporate parking, retail shops, lobbies, offices, and apartments, each requiring a different type of heating and cooling system.

The zoning of a building is significant in the early stages of design because it may suggest a choice of heating and cooling system: Room-by-room zoning—for an apartment building, for example—suggests a system that does not require centralized ductwork, such as all-water fan-coil terminals or packaged terminal units. Zoning may also have an impact on where the major equipment spaces are placed. It often makes sense to put major equipment on the "seam" between two zones. An example of this might be placing the major heating and cooling equipment on the second or third floor of a multiuse downtown building, above retail and lobby spaces and below multiple floors of office space.

CENTRAL SYSTEMS VERSUS LOCAL SYSTEMS

In a *central system*, heat is supplied to a building or extracted from it by large equipment situated in one or several large mechanical spaces. Air or water is heated or cooled in these spaces and distributed to the inhabited areas of the building by ductwork or piping, to maintain comfortable conditions.

In a *local system*, independent, self-contained pieces of heating and cooling equipment are situated throughout the building, one or more in each room.

Central systems are generally quieter than local systems and offer better control of indoor air quality. Central equipment tends to last longer than local equipment and, because it is located in its own dedicated spaces, is easier to service. Local systems occupy less space in a building than central systems because they do not require dedicated spaces and extensive ductwork or piping. However, the space they do occupy tends to be located within the occupied areas being served by the equipment. They are often more economical to buy and install. They can be advantageous in buildings that have many small spaces requiring individual temperature control.

Pages 174–183 describe choices of central heating and cooling systems for large buildings. Local systems are described on page 184.

FUELS

Energy is delivered to a building heating and cooling system in the form of gas, oil, electricity, steam, or hot water. Gas and oil are readily available fuels and efficient sources of energy. However, they are also nonrenewable fossil fuels. Their extraction from the earth entails environmental degradation and when they are consumed, they produce carbon dioxide, a major contributor to global climate change.

On the building site, electricity is a clean source of energy. It is distributed through compact lines, and the equipment it powers tends to be smaller and quieter than fuel-burning equipment. The environmental footprint of electrical power depends on how it is produced. Most electricity is generated far from the building site in fossil-fueled power plants which, themselves, produce carbon dioxide. The generation of electrical power from renewable resources, such as wind, solar, or hydro, is mostly free from carbon dioxide emissions, although there are other environmental impacts associated with each of these. The generation of electricity with nuclear power is mostly free of carbon dioxide emissions, but is not without its own uniquely hazardous environmental risks. When the efficiencies of remote electrical power generation and distribution are considered, electricity converted directly into heat is less efficient than systems that rely on the burning of oil or gas on-site. However, when electricity is used to power air conditioners or heat pumps, efficiencies are much higher. On-site production of electricity using photovoltaic arrays is also becoming an increasingly viable option for zero-carbon power generation.

Hot water and steam can be produced on the building site, by oil- or gas-fired boilers, or they may be generated off-site. Some large cities supply utility-generated pipeline steam to downtown commercial areas. Similarly, some large building complexes, such as university campuses, supply hot and chilled water to buildings via underground pipelines from a central boiler/chiller plant. Both hot water and steam transport energy efficiently, the heat exchange equipment on which they rely is more compact than the fuel-burning boilers that would otherwise be required, and when these sources of energy are produced at a central plant, no chimneys are required in the buildings that they serve.

Passive heating and cooling systems rely on naturally available, renewable sources of energy such as the sun and the wind. For more information about passive heating and cooling systems, see pages 221–238.

MEANS OF DISTRIBUTION

In central systems, the distribution of heating and cooling energy within the building depends on the circulation of air, water, or both to the inhabited spaces.

- In *all-air systems*, central fans circulate conditioned air to and from the spaces through long runs of *ductwork*.
- In *air and water systems*, air is ducted to each space. Heated and chilled water are also piped to each space, where they are used to modify the temperature of the circulated air at each outlet, to meet local demands. Air and water systems circulate less air than all-air systems, which makes them more compact and easier to house in a building.
- In *all-water systems*, air is circulated locally rather than from a central source, so ductwork is eliminated. Only heated and chilled water are furnished to each space. The water piping is much smaller than equivalent ductwork, making all-water systems the most compact of all.

All-air systems offer good control of interior air quality. The central air-handling equipment can be designed for precise control of fresh air, filtration, humidification, dehumidification, heating, and cooling. When the outdoor air is cool, an all-air system can switch to an *economizer cycle*, in which it cools the building by directly circulating outdoor air. All-air systems concentrate maintenance activities in unoccupied areas of the building because there are no water pipes, condensate drains, valves, fans, or filters outside the mechanical equipment rooms.

Air and water systems use heated and chilled water to deliver the bulk of the heat energy to and from occupied spaces, and supply only as much air as is needed to meet requirements for fresh air and to control humidity. Because water pumped through pipes can transport heat energy much more efficiently than can air pushed through ducts by fans, air and water systems have the potential to operate at higher efficiencies than all-air systems. In addition, because the air supply component of the system does not need to adjust to changes in heating and cooling load, provision of fresh air and control of humidity can be maintained more consistently across a wider range of heating and cooling load conditions. The result is more consistent occupant comfort. However, air and water systems are more complicated than all-air systems, and more maintenance activity may be necessary in occupied parts of the building.

All-water systems eliminate the need for any central ductwork, and thereby require the least amount of space of all centralized systems. However, these systems are more limited in their ability to manage the supply of fresh air or control humidity. All-water systems are frequently used in combination with other systems that perform these other functions.

DEDICATED OUTDOOR AIR SYSTEMS

A *dedicated outdoor air system* (*DOAS*) delivers just as much conditioned outdoor air to occupied spaces as is needed to meet fresh air ventilation requirements and control interior humidity levels, while the bulk of the spaces' heating or cooling is met by some other system. By divorcing ventilation requirements from heating and cooling demands (also called the *sensible heat and cooling loads)*, a DOAS can maintain consistently high indoor air quality. At the same time, the heating or cooling system gains increased latitude to meet varying loads without adversely affecting the supply of fresh, conditioned air. Because the two parts of the system—fresh air and temperature control—work independently, both can operate more consistently at maximum effectiveness and efficiency.

A DOAS relies on 100% fresh air. Exhaust air is not recirculated, lessening the risk of the spread of air pollutants or contaminants from one part of a building to another. It is also common with a DOAS to implement energy recovery of some type, between the exhaust and supply air streams, to improve efficiency. (See, for example, the heating and cooling system diagram on page 178.)

A DOAS can work in combination with almost any heating and cooling system. In new buildings, it may easily be combined with an all-water system, such as fan-coil terminals (page 180) or hydronic radiant heating and cooling (page 183). Active chilled beams (pages 178–179) are an example of an air and water system in which the DOAS and chilled beams combine into an integrated system. DOAS can also work with all-air systems. In such cases, the DOAS supplies the fresh air to occupied spaces, while a second air system recirculates and conditions space air as needed to maintain comfortable ambient conditions. In all cases, the goal of implementing a DOAS is to improve the quality of the interior environment while reducing energy costs.

When using the chart on page 218 to estimate the sizes for air-handling components of a dedicated outdoor air system, cooling air volumes read from the chart should be reduced in the range of 50% to 70% to account for the lower air volumes required for this type of system.

SELECTING HEATING AND COOLING SYSTEMS FOR LARGE BUILDINGS

The following pages will help you choose a heating and cooling system for your building and make preliminary estimates for the sizes of its parts.

You can make one or more preliminary system choices using the table on pages 166–167, which relates common choices of heating and cooling systems to various building types. You can refine your list of choices by referring to pages 168–171, which describe various possible design criteria and list systems and their variations well-suited to each of these. The table on pages 172–173 presents this same criteria information in tabular form. Lastly, on pages 174–184, individual systems, variations on those systems, and the major components required by each are discussed in greater depth.

To estimate the space required by the system you select, first look at the list of major components and their sizes included within the system description. Then, for components common to many of the systems, use the sizing charts on pages 216–219.

COMMON CHOICES OF HEATING AND COOLING SYSTEMS FOR LARGE BUILDINGS

	ALL-AIR SYSTEMS		AIR AND WATER SYSTEMS	ALL-WATER SYSTEMS			
OCCUPANCY	**Variable Air Volume (VAV) (pages 174–175)**	**Constant Air Volume (CAV) (pages 176–177)**	**Active Chilled Beams (pages 178–179)**	**Fan-Coil Terminals (page 180)**	**Closed-Loop Heat Pumps (page 181)**	**Hydronic Convectors (heating only) (page 182)**	**Hydronic Radiant Heating and Cooling (page 183)**
Apartments				●	●	●	
Arenas, Exhibition Halls	●	●					●
Auditoriums, Theaters	●	●					●
Factories	●	●		●			●
Hospitals	●		●	●			
Hotels, Motels, Dormitories	●			●	●	●	
Laboratories	●	●	●				
Libraries	●		●			●	●
Nursing Homes	●		●	●			
Offices	●		●	○	○	●	●
Places of Worship	●	●				●	●
Schools	●		○	●	○	●	
Shopping Centers	●						
Stores	●						

● Frequently used
○ Less frequently used

COMMON CHOICES OF HEATING AND COOLING SYSTEMS FOR LARGE BUILDINGS

LOCAL SYSTEMS	PASSIVE SYSTEMS			
Packaged Terminal Units or Through-the-Wall Units (page 184)	**Passive Solar Heating (pages 228–230)**	**Natural Ventilation Cooling (pages 231–233)**	**Thermal Mass Cooling (pages 234–236)**	**Evaporative Cooling (pages 237–238)**
●		○	○	○
●		○	○	○
	○	○	○	○
●				
	○	○	○	○
	○	○	0	
	○	○	○	○

DESIGN CRITERIA FOR THE SELECTION OF HEATING AND COOLING SYSTEMS FOR LARGE BUILDINGS

If you wish to minimize the first cost of the heating and cooling system:	Choose the simplest possible all-air system: Variable air volume (VAV) (pages 174–175) VAV reheat (page 175) Constant air volume (pages 176–177) Single-packaged units (pages 192–194) or choose a system that involves no centralized ductwork or piping: Packaged terminal units (page 184) Ductless split-packaged systems (pages 192–194)
If you wish to minimize operating cost and energy consumption:	Choose a central system that heats and cools spaces with maximum efficiency: Variable air volume (VAV) (pages 174–175) VAV induction (page 175) Active chilled beams (pages 178–179) Passive chilled beams (page 179) Hydronic radiant heating and cooling (page 183) or choose a system that uses ambient heat from the surrounding environment: Closed-loop heat pumps (page 181) Ground-source heat pumps (page 183) Packaged heat pump units (page 193) or add energy storage to the heating and cooling system: Thermal energy storage (page 190) or in medium-sized or smaller buildings, consider a passive system: Passive solar heating (pages 228–230) Natural ventilation cooling (pages 231–233) Thermal mass cooling (pages 234–236) Evaporative cooling (pages 237–238)
If you wish to maximize control of air quality and air velocity:	Choose systems that control air separately from temperature: Variable air volume (VAV) induction (page 175) Fan-powered VAV (page 175) Dual-duct VAV (page 175) Active chilled beams (pages 178–179) Any dedicated outdoor air system (page 165) or choose systems that provide constant high volumes of air: Constant air volume (CAV) (pages 176–177) Multizone CAV (page 177)
If you wish to maintain occupant comfort in spaces that undergo large changes in heating and cooling load:	Choose a system that can respond to large changes in heating and cooling load: Variable air volume (VAV) reheat (page 175) VAV induction (page 175) Fan-powered VAV (page 175) Dual-duct VAV (page 175) Fan-coil terminals (page 180)

DESIGN CRITERIA FOR THE SELECTION OF HEATING AND COOLING SYSTEMS FOR LARGE BUILDINGS

If you wish to minimize system noise:	Choose a system that operates at low air velocities and whose moving parts are distant from the occupied spaces, such as: Variable air volume and any variation except fan-powered (pages 174–175) Constant air volume (CAV) (pages 176–177) Multizone CAV (page 177) Active chilled beams (pages 178–179) Passive chilled beams (page 179) Hydronic convectors (page 182) Hydronic radiant heating and cooling (page 183) or in medium-sized or smaller buildings, consider a passive system: Passive solar heating (pages 228–230) Thermal mass cooling (pages 234–236)
If you wish to minimize the visual obtrusiveness of the heating and cooling system:	Choose a system that has minimal hardware in the occupied spaces of the building, such as: Any central all-air or air and water system (pages 174–179) Hydronic radiant heating and cooling (page 183) Single-packaged units (pages 192–194) or in medium-sized or smaller buildings, consider a passive system: Passive solar heating (pages 228–230) Natural ventilation cooling (pages 231–233) Thermal mass cooling (pages 234–236) Evaporative cooling (pages 237–238)
If you wish to maximize the flexibility of rental space and the adaptability of the heating and cooling system to space reconfiguration over time:	Choose a central air system that has minimal hardware in the occupied spaces of the building and that can provide local or zoned control over temperature, such as: Variable air volume and any variation (pages 174–175) or choose an all-water system that allows easy temperature control of individual spaces: Fan-coil terminals (page 180) Hydronic convectors (page 182) or choose a system that has no centralized ductwork water piping: Packaged terminal units (page 184) Ductless split-packaged systems (pages 193–194)
If you wish to condition a large, single-story, open space, for example a warehouse, gymnasium, or box retail store, with the simplest possible system:	Choose a system that is self-contained, easily scalable, and takes up minimal interior space, such as: Single-packaged units (pages 192–194)

DESIGN CRITERIA FOR THE SELECTION OF HEATING AND COOLING SYSTEMS FOR LARGE BUILDINGS

If you wish to minimize the floor space used for the mechanical system:

Choose an air and water system that works with smaller-sized air-handling components, such as:
- Active chilled beams (pages 178–179)
- Passive chilled beams (page 179)

or a system in which many of the components are located outside of the building:
- Any packaged central system (pages 192–194)

or a local system that has no ductwork or water piping, such as:
- Packaged terminal units (page 184)

or an all-water system:
- Fan-coil terminals (page 180)
- Hydronic convectors (page 182)
- Hydronic radiant heating and cooling (page 183)

or in medium-sized or smaller buildings, consider a passive system:
- Passive solar heating (pages 228–230)
- Natural ventilation cooling (pages 231–233)
- Thermal mass cooling (pages 234–236)
- Evaporative cooling (pages 237–238)

If you wish to minimize the floor-to-floor height of the building:

Choose an all-air or air and water system that works with smaller-sized ductwork, such as:
- Variable air volume induction (page 175)
- Active chilled beams (pages 178–179)
- Passive chilled beams (page 179)

Choose a local system that has no centralized ductwork or piping, such as:
- Ductless split-packaged systems (page 193)
- Packaged terminal units (page 184)

or an all-water system:
- Fan-coil terminals (page 180)
- Hydronic convectors (page 182)
- Hydronic radiant heating and cooling (page 183)

or in medium-sized or smaller buildings, consider a passive system:
- Passive solar heating (pages 228–230)
- Natural ventilation cooling (pages 231–233)
- Thermal mass cooling (pages 234–236)
- Evaporative cooling (pages 237–238)

DESIGN CRITERIA FOR THE SELECTION OF HEATING AND COOLING SYSTEMS FOR LARGE BUILDINGS

If you wish to minimize maintenance requirements of the heating and cooling system:	Choose systems that are very simple and have few moving parts in the occupied spaces of the building: Variable air volume (VAV) (pages 174–175) VAV induction (page 175) Constant air volume (CAV) (pages 176–177) Multizone CAV (page 177) Active chilled beams (pages 178–179) Passive chilled beams (page 179) Hydronic convectors (page 182) Hydronic radiant heating and cooling (page 183) Single-packaged units (pages 192–194) or in medium-sized or smaller buildings, consider a passive system: Passive solar heating (pages 228–230) Natural ventilation cooling (pages 231–233) Thermal mass cooling (pages 234–236) Evaporative cooling (pages 237–238)
If you wish to avoid having a chimney in the building:	Choose systems that rely on heated or cooled water from a heat pump, such as: Active chilled beams (pages 178–179) Hydronic radiant heating and cooling (page 183) or choose systems that are electrically powered: Closed-loop heat pump (page 181) An all-water system with ground source heat pump (page 183) Any packaged central system, with heat pump where heating is required (pages 192–194) Packaged terminal units (page 184) or in medium-sized or smaller buildings, consider a passive heating system: Passive solar heating (pages 228–230)
If you wish to maximize the speed of construction:	Choose systems that can be installed by a single trade, such as: Packaged terminal units (page 184) Packaged central systems (pages 192–194)

HEATING AND COOLING SYSTEMS FOR LARGE BUILDINGS: DESIGN CRITERIA SUMMARY

GIVE SPECIAL CONSIDERATION TO THE SYSTEMS INDICATED IF YOU WANT TO:	Variable Air Volume (VAV) (page 174)	VAV Reheat (page 175)	VAV Induction (page 175)	Fan-Powered VAV (page 175)	Dual-Duct VAV (page 175)	Constant Air Volume (CAV) (page 176)	Multizone CAV (page 177)	Active Chilled Beams (page 178)	Passive Chilled Beams (page 179)	Fan-Coil Terminals (page 180)
Minimize first costs	●	●				●				
Minimize operating costs and energy consumption	●		○					●	●	
Maximize control of air velocity and air quality			○	●	○	○	○	●		
Maintain comfort with large heating and cooling load changes		●	○	●	○					●
Minimize system noise	●	●	○		○	●	○	●	●	
Minimize visual obtrusiveness	●	●	○	●	○	●	○	○	○	
Maximize flexibility of space reconfiguration	●	●	○	●	○					●
Condition a large, single-story, open space										
Minimize floor space used for the heating and cooling systems								●	●	○
Minimize floor-to-floor height			○					●	●	○
Minimize system maintenance	●		○			●	○	●	●	
Avoid having a chimney								●		
Maximize the speed of construction										

● Frequently used
○ Less frequently used

HEATING AND COOLING SYSTEMS FOR LARGE BUILDINGS: DESIGN CRITERIA SUMMARY

Close-Loop Heat Pumps (page 181)	**Hydronic Convectors (heating only) (page 182)**	**Hydronic Radiant Heating and Cooling (page 183)**	**Central Single-Packaged Units (page 192)**	**Packaged Heat Pump Units (page 193)**	**Ductless Split-Packaged Units (page 193)**	**Packaged Terminal Units (page 184)**	**Passive Solar Heating (page 228)**	**Natural Ventilation Cooling (page 231)**	**Thermal Mass Cooling (page 234)**	**Evaporative Cooling (page 237)**
			●		●	●				
●		●		●			●	●	●	●
	●	●					●		●	
		●	●				●	●	●	●
	●				●	●				
			●							
	●	●	●	●	●	●	●	●	●	●
	●	●			●	●	●	○	●	●
	●	●	●				●	●	●	●
●		●	●	●	●	●	●			
			●	●	●	●				

Description

Air is conditioned (mixed with a percentage of outdoor air, filtered, heated or cooled, and humidified or dehumidified) at a central source. Supply fans circulate the conditioned air through ducts to the occupied spaces of the building, while return fans exhaust air to the exterior or recirculate it into the air-handling system. In each zone, a thermostat connected to the VAV terminal's controller monitors the air temperature and regulates the volume of air discharged from the terminal to diffusers in that zone.

Typical Applications

VAV is the most versatile and most widely used system for heating and cooling large buildings.

Advantages

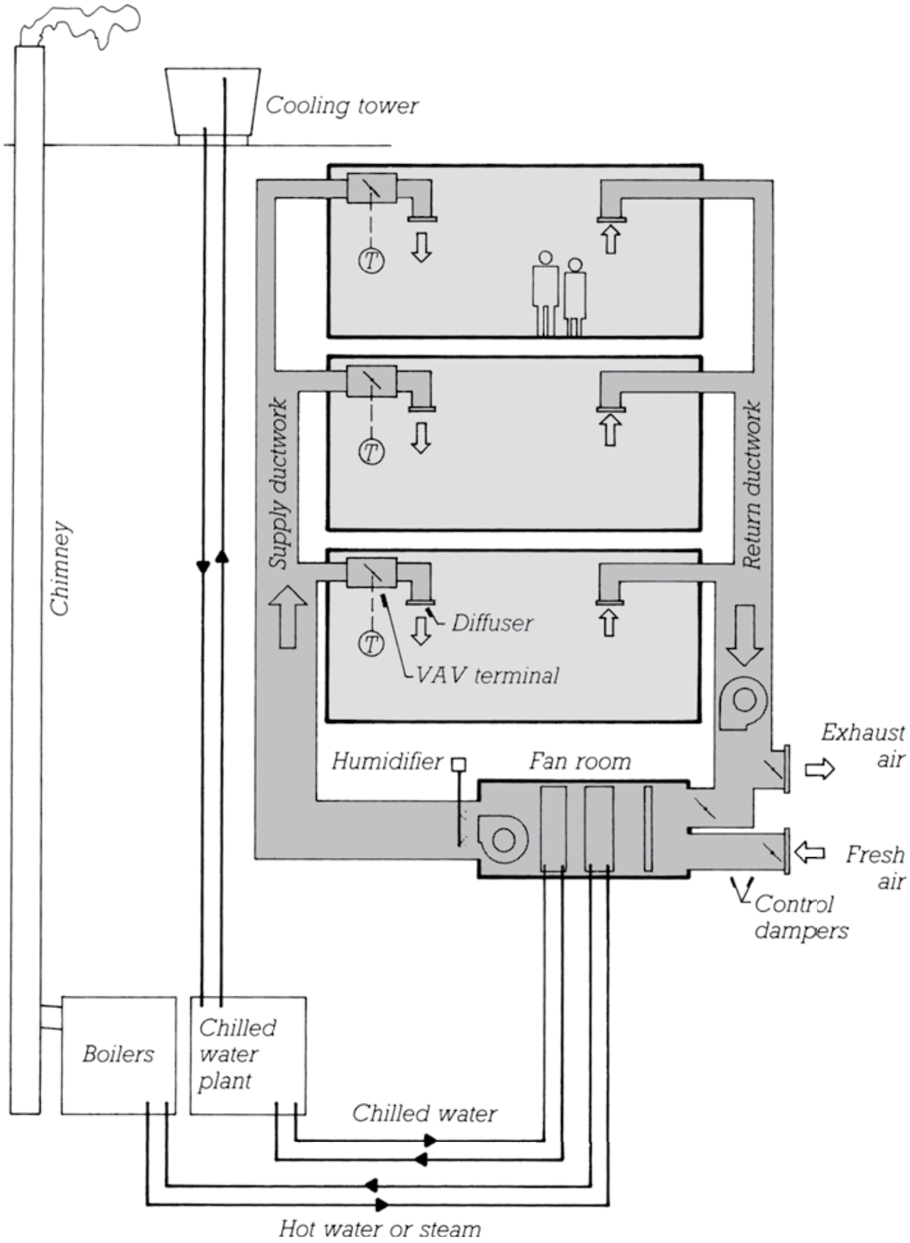
This system offers a high degree of local temperature control at moderate cost. It is economical to operate and virtually self-balancing.

Disadvantages

VAV is limited in the range of heating or cooling demand that may be accommodated within a single system. When one area of a building needs heating while another needs cooling, a VAV system cannot serve both areas without help from a secondary system (see Variations, following).

Major Components

The major components of a VAV system are as follows: boilers and chimney, chilled water plant, cooling tower, fan room, outdoor fresh air and exhaust louvers, vertical supply and return ducts, horizontal supply and return ducts, a VAV terminal for each zone, supply diffusers, and return grilles. (For an illustration of typical diffusers and grilles, see page 215.)



VARIABLE AIR VOLUME (VAV)

Alternately, in buildings of moderate size, a packaged system may be used in place of all components other than ducts, VAV terminals, diffusers, and grilles. A single-packaged system, incorporating all central components in a single metal box, may be installed on the roof or outside an exterior wall; or a split-packaged system may be installed, with a compressor and condensing unit in an outdoor box, and an evaporator and air-handling unit in an indoor box. Multiple packaged systems are often used to serve buildings that are large in horizontal extent. For more detailed information on packaged units, see pages 192–194.

Sizing the Components

The VAV terminal is usually concealed above a suspended ceiling. It is approximately 8 to 11 in. (200 to 280 mm) high for zones up to 1500 sq ft (150 m^2) in area, and up to 18 in. (460 mm) high for zones up to 7000 sq ft (700 m^2). Its horizontal dimensions vary with its capacity, up to a maximum length of about 6 ft (1.8 m). To size the other components of a VAV system, use the charts on pages 216–219.

Variations

1. *Variable air volume reheat systems* are identical to standard VAV systems up to the point at which air enters the local ductwork for each zone. In reheat systems, the air then passes through a reheat coil before it is distributed to the local diffusers. The reheat coil may be either an electric resistance coil or a pipe coil that carries hot water circulated from the boiler room. A local thermostat controls the flow of water or electricity through the reheat coil (along with modulation of the air supply), allowing for close individual control of room temperature. This is a common variation used to overcome the inability of simple VAV systems to cope with a wider range of heating and cooling demands. A VAV reheat system may be used, for example, to manage the large differences in cooling and heating demands between interior spaces and those adjacent to exterior walls or, especially, adjacent to large areas of windows.

2. *Variable air volume induction systems* deliver a smaller volume of air, conditioned to a colder temperature than in conventional VAV systems, to VAV induction terminals. As the conditioned air (called *primary air*) passes through the VAV terminal, room air (called *secondary air*) is drawn into the terminal and mixed with the primary air. This mixture of conditioned and room air is then delivered to the supply diffusers served by each VAV terminal. VAV induction systems can achieve higher efficiencies and maintain more consistent air temperatures than standard VAV systems. They are an especially good choice for spaces that experience wide ranges of high and low cooling loads, where they can better maintain comfortable temperatures while continuing to supply adequate volumes of fresh air to such spaces. Fans and ductwork in VAV induction systems may be reduced in size by as much as 30% from those in standard VAV systems.

3. *Fan-powered variable air volume terminals* function similarly to VAV induction terminals, blending secondary room air with primary air from the air-handling system at the terminal, but using a fan within the terminal rather than induction. Like VAV reheat terminals, they may also include reheat coils. Fan-powered terminals can improve system efficiency and provide better air distribution within occupied spaces. A common application is to provide additional cooling or heating at the building perimeter zone.

4. *Dual-duct variable air volume systems* pair side-by-side ducts carrying both heated and cooled air to each zone in the building. At each zone, the two airstreams are proportioned and mixed under thermostatic control to achieve the desired room temperature. This variation gives excellent local temperature control, but requires an expensive and space-consuming dual system of ductwork and is not energy efficient.

5. *Underfloor air distribution (UFAD)* systems distribute the conditioned supply air from beneath raised access floors. For more information on UFAD, see pages 213–214.

6. *Air-to-air energy recovery* recovers heat energy in the exhaust air stream of the air-handling system and returns it to the supply air stream, increasing the operating efficiency of the heating and cooling system. The choice of recovery technology depends on factors such as (1) whether only sensible heat (related to difference in temperature) or also latent heat (related to change in phase between water in liquid and vapor states) are to be recovered, (2) the degree to which cross-contamination between the exhaust and supply air streams can be tolerated, (3) the climatic conditions under which the recovery device must operate, and (4) the space available for the device. Energy recovery rates in the range of 25% to 80% are achievable. Energy recovery is also a requirement of many building energy-use standards. An example of total energy wheel heat recovery is illustrated in the figure on page 178.

Description

Air is conditioned (mixed with a percentage of outdoor air, filtered, heated or cooled, and humidified or dehumidified) at a central source. Supply and return fans circulate the air through ducts to the occupied spaces of the building. A master thermostat connects to controllers that adjust the flow of hot and cold water to the central heating and cooling coils, thereby regulating the temperature of the air flowing through the system.

Typical Applications

CAV is typically used in spaces that have large open areas, few windows, and uniform loads, such as lobbies, department stores, theaters, auditoriums, gymnasiums, and exhibition halls.

Advantages

This system offers a high degree of control of air quality. It is comparatively simple and easy to maintain.

Disadvantages

The entire area served by the system is normally a single zone, with no possibility for individual temperature control of separate zones. CAV systems use considerably more fan energy than VAV systems.

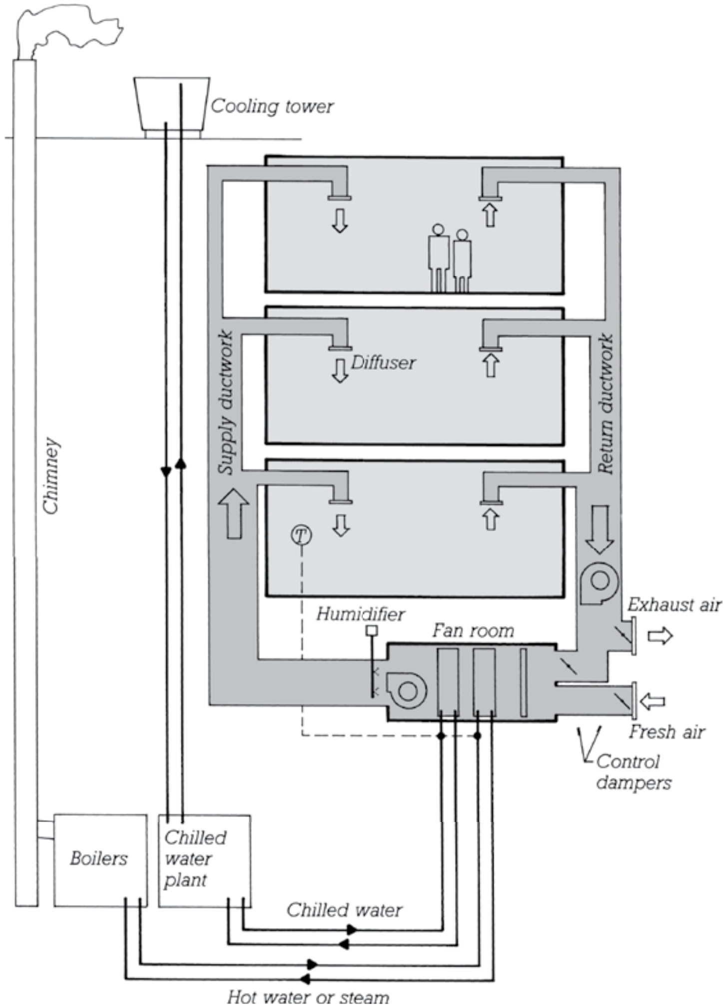
Major Components

The major components of a CAV system are as follows: boilers and chimney, chilled water plant, cooling tower, fan room, outdoor fresh air and exhaust louvers, vertical supply and return ducts, horizontal supply and return ducts, supply diffusers, and return grilles. (For an illustration of typical diffusers and grilles, see page 215.)

Alternately, in buildings of moderate size, a packaged system may be used in place of all components other than ducts, VAV terminals, diffusers, and grilles. A single-packaged system, incorporating all central components in a single metal box, may be installed on the roof or outside an exterior wall; or a split-packaged system may be installed, with a compressor and condensing unit in an outdoor box, and an evaporator and air-handling unit in an indoor box. Multiple packaged systems are often used to serve buildings that are large in horizontal extent. For more detailed information on packaged units, see pages 192–194.

Sizing the Components

For the dimensions of these components, see the charts on pages 216–219.



CONSTANT AIR VOLUME (CAV)

Variations

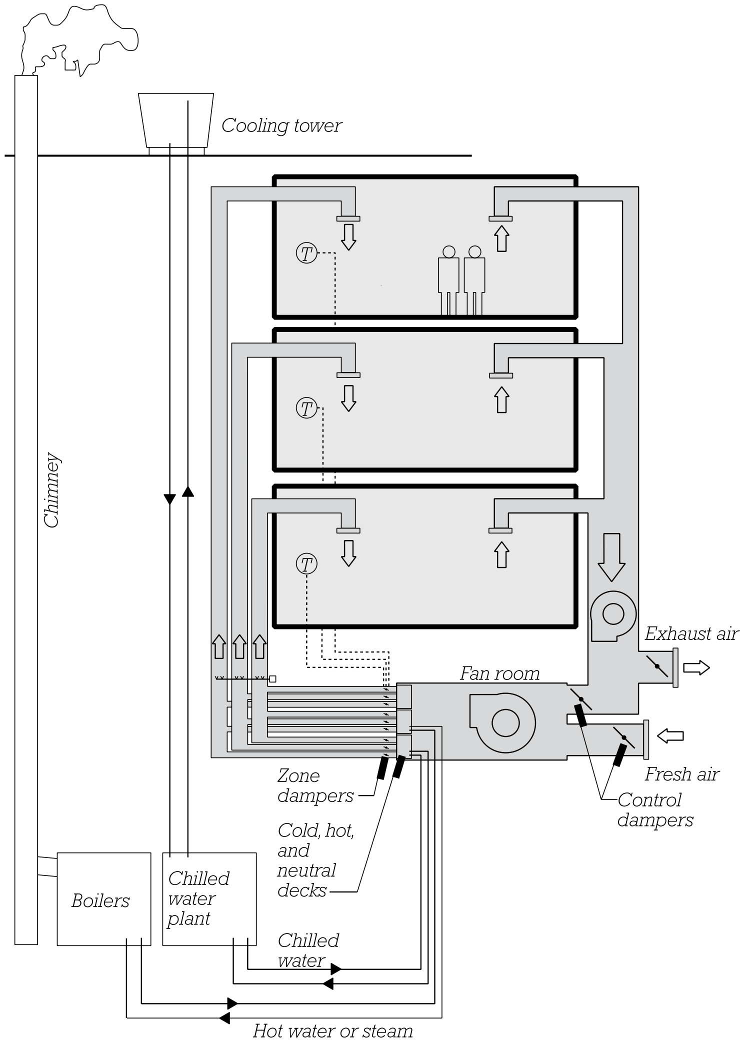
1. *Furnaces* are indoor units that incorporate a source of heat and an air- circulating fan into a single metal box. The source of heat may be a gas burner, an oil burner, an electric resistance coil, or a heat pump coil. Cooling coils may also be incorporated if desired. The capacity of furnaces is limited to such an extent that they are used mostly in single-family houses and other very small buildings; multiple furnaces are sometimes used to heat and cool somewhat larger buildings. For a more extended discussion of furnaces, see pages 247–249.

2. *Multizone constant air volume systems* supply air at different temperatures through separate ducts to separate areas within a building. This allows a single system to simultaneously meet the demands of spaces with differing cooling and heating needs.

In the fan room, supply air passes through two or three *decks*: one chilled, one heated, and a possible third neutral deck that does not change the temperature of air passing through it. Each duct serving a different zone receives a different blend of air from the decks. Ducts supplying a zone requiring cooling receive a greater proportion of chilled air. Ducts supplying a zone requiring heating receive a greater proportion of heated air. The blending of air from the decks is controlled by coordinated sets of zone dampers for each supply duct that are adjusted in response to signals from thermostats in each zone.

In a three-deck system, spaces that require cooling receive a mixture of chilled air and untempered air from the cold and neutral decks. Spaces requiring heating receive a mixture of air from the hot and neutral decks. But heated and cooled air are never directly mixed. In a two-deck system, heated and cooled air must be combined to adjust the temperature of the supply air stream. This direct mixing of heated and cooled air makes two-deck systems less energy efficient than three-deck systems.

Multizone systems require a large amount of space for ductwork in the vicinity of the fan, so they are generally restricted to a small number of zones with short runs of ductwork. They are best suited to museums and other buildings requiring very precise control of air temperatures throughout separate areas. Packaged multizone units are also available.



MULTIZONE SYSTEM

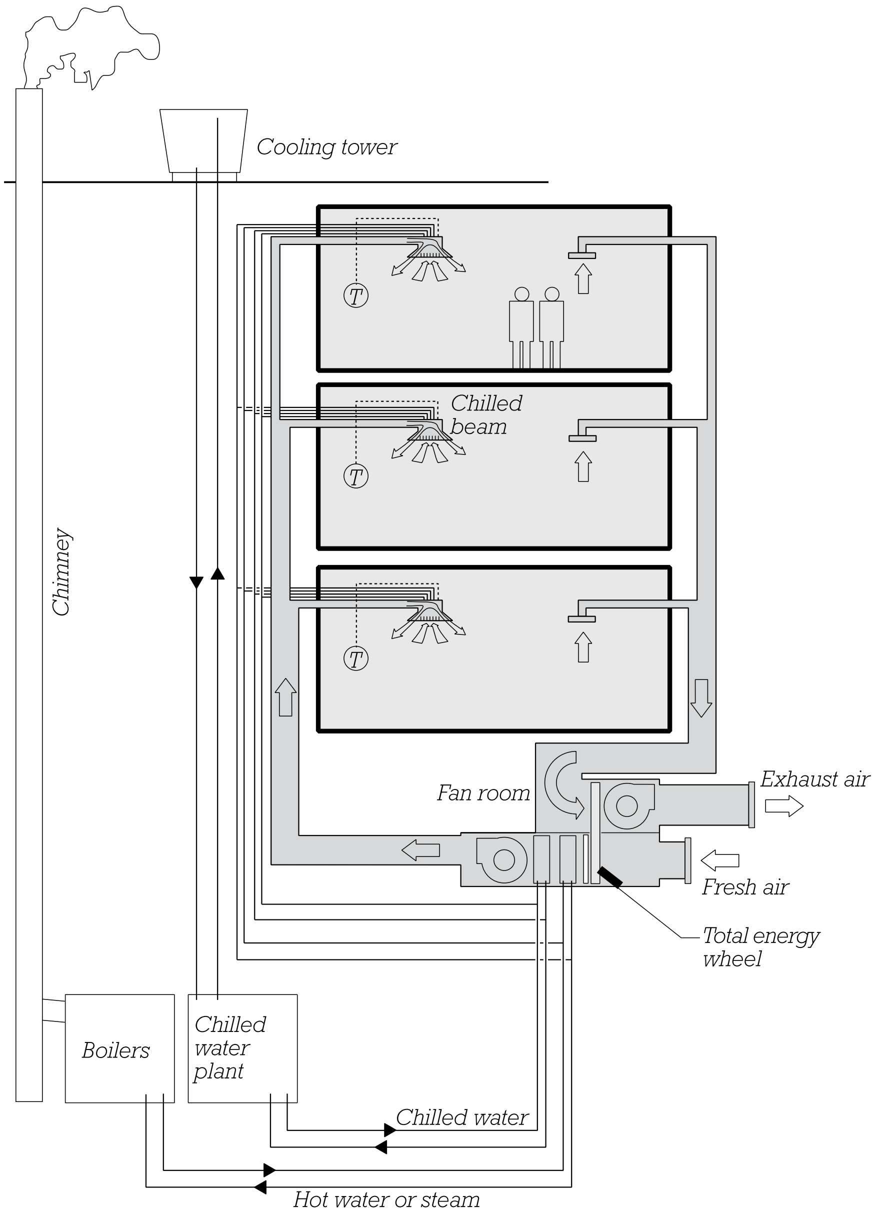
3. *Underfloor air distribution (UFAD)* systems distribute the conditioned supply air from beneath raised access floors. For more information on UFAD, see pages 212–213.

4. *Air-to-air energy recovery* captures heat energy in the exhaust air stream of the air-handling system and returns it to the supply air stream, increasing the operating efficiency of the heating and cooling system. The choice of recovery technology depends on factors such as (1) whether only sensible heat (related to difference in temperature) or also latent heat (related to change in phase between water in liquid and vapor states) are to be recovered, (2) the degree to which cross-contamination between the exhaust and supply air streams can be tolerated, (3) the climatic conditions under which the recovery device must operate, and (4) the size of the space available for the device. Energy recovery rates in the range of 25% to 80% are achievable. Energy recovery is a requirement of many building energy-use standards. An example of total energy wheel heat recovery is illustrated in the figure on page 178.

Description

Outside air is conditioned at a central source and then circulated through ducts to *chilled beams*, most frequently mounted in the ceilings of occupied spaces of the building. In the chilled beams, air discharging from the duct (called *primary air*) draws a larger volume of room air (*secondary air*) through the device, where it passes over a coil that is either heated or cooled by water piped from the boiler room or chilled water plant. The primary air (roughly one-third of the total airflow) and the tempered secondary room air (the remaining two thirds) mix and then are discharged into the room. Despite their name, chilled beams can provide both cooling and heating.

Air handling is usually constant velocity. Temperature control is provided by local thermostats, which control the flow of hot or cold water to the coils within the chilled beams. The air-handling system is a dedicated outdoor air system (see page 165), and relies on 100% outside air. Because exhaust air is not recirculated, energy recovery between exhaust and supply air streams is common, as with the total energy wheel shown in the accompanying diagram.



ACTIVE CHILLED BEAM SYSTEM

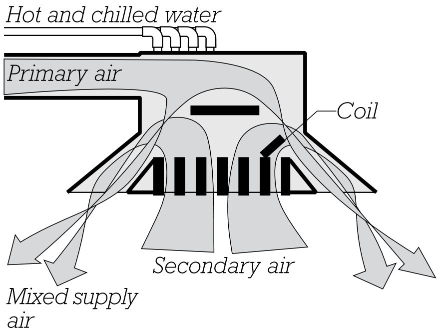
Typical Applications

Active chilled beam systems are well suited to spaces with moderate fresh air and dehumidification requirements, such as office buildings, schools, and residential hotels and dormitories. They can also be a good choice for spaces with high demands for cooling, for example, cooling-load driven laboratories.

Advantages

In comparison to all-air systems, active chilled beams can be quieter, provide more constant airflow, and better control humidity, all of which contribute to improved occupant comfort. Because the majority of the heat is transported as piped water, active chilled beam systems can operate more efficiently than comparable all-air systems, and the fans, ductwork, and other parts of the air-handling system may be as much as 70% smaller. This reduces the building area that must be set aside for these components, lessens the height required above ceilings for ductwork, and allows lower floor-to-floor heights.

Exhaust air is normally not recirculated, reducing the chance of transporting air pollutants or contaminants from one part of a building to another. Because the piped water is closer to room temperature than in all-water systems, renewable or efficient energy sources such as heat pumps, geothermal exchange, or solar hot water can



ACTIVE CHILLED BEAM

be used in place of conventional boilers and chillers. The absence of fans, other moving parts, and condensate drip pans in occupied spaces reduces maintenance costs and the risk of mold or bacteria growth in these areas.

Disadvantages

Active chilled beam systems may have higher installation costs than comparable all-air systems. They require more wet piping, with the possibility of leaks, in occupied portions of the building. They are not suitable for spaces that require very high levels of dehumidification or unusually high volumes of fresh air. They have limited heating capacity. In buildings with high ceilings or high heating demands, a supplemental heating system, such as hydronic convectors at exterior walls (see page 182), may be required.

Major Components

The major components of an active chilled beam system are as follows: boilers, chimney, chilled water plant and cooling tower, fan room, outdoor fresh air and exhaust louvers, vertical supply and return ducts, horizontal supply and return ducts, vertical supply and return piping, horizontal supply and return piping, and chilled beam units. Alternatively, heated and cooled water may be supplied by central heat pumps in place of boilers, chimney, chilled water plant, and cooling tower.

Sizing the Components

Ceiling-mounted active chilled beams typically come in sizes that coordinate with standard modular ceiling grids, with widths of 1 or 2 ft (305 or 610 mm), and lengths from 2 to 10 ft (610 to 3048 mm). Unit heights may range from approximately 7 to 12 in. (178 to 305 mm), with primary air inlets located on the top or sides. Wall-mounted or under-window floor-mounted active chilled beams are also available. For the dimensions of the other components of the system, see the charts on pages 216–219. When using the chart on page 218 to estimate the sizes of air-handling components, cooling air volumes should be reduced in the range of 50% to 70% from the values given in the chart, to account for the lower air volumes required for this type of system.

Variations

1. *Variable air volume active chilled beam systems* can adjust the flow of primary air to individual or groups of active chilled beams. This allows for the reduction of primary airflow during off-peak conditions, avoids overcooling, and increases energy efficiency. However, adding variable air volume control to the chilled beams increases installation costs and mechanical complexity.

2. *Passive chilled beams* are always mounted near the ceiling and rely on the circulation of room air through the beam, without the supply of any conditioned primary air. They are used for cooling only and are connected to two-pipe chilled water systems. Passive chilled beams work by natural convection. Warm air near the ceiling is drawn into the chilled beam, is cooled as it passes through the coils, and then exits the beam and descends toward the floor due to its greater density in relation to the surrounding air. Because passive chilled beams provide only cooling, requirements for fresh air, humidity control, and heating must be met by other means. For example, passive chilled beams may be used in combination with an underfloor air distribution system that satisfies these other needs. (See pages 212–213 for more information on underfloor distribution systems.) Passive chilled beams can also be used in combination with active beams to add cooling capacity, provide more uniform distribution of conditioned air, or concentrate extra cooling in high-demand areas, such as at the building perimeter.

3. *Two-pipe active chilled beam systems*, which rely on a single pair of pipes for chilled and hot water supply and return, have lower installation costs in comparison to four-pipe systems. With less piping, the risk of water leakage in occupied parts of the building is also somewhat reduced. However, two-pipe systems offer less heating and cooling flexibility than four-pipe systems, because they can supply cold water for cooling or hot water for heating, but not both simultaneously to separate areas in the building.

Description

Hot and chilled water are piped to fan-coil terminals. At each terminal, a fan draws a mixture of room air and outdoor air through a filter and blows it across the heated or chilled coil and then back into the room. A thermostat controls the flow of hot and chilled water to the coils to maintain a comfortable room temperature. Condensate that drips from the chilled coil is caught in a pan and removed through drainage piping (not shown in the diagram). Air exhaust from the space (also not shown) is provided separately, for example, with toilet room exhaust fans.

Typical Applications

These systems are well suited for buildings with many zones, all located on exterior walls, such as schools, hotels, motels, apartments, and office buildings.

Advantages

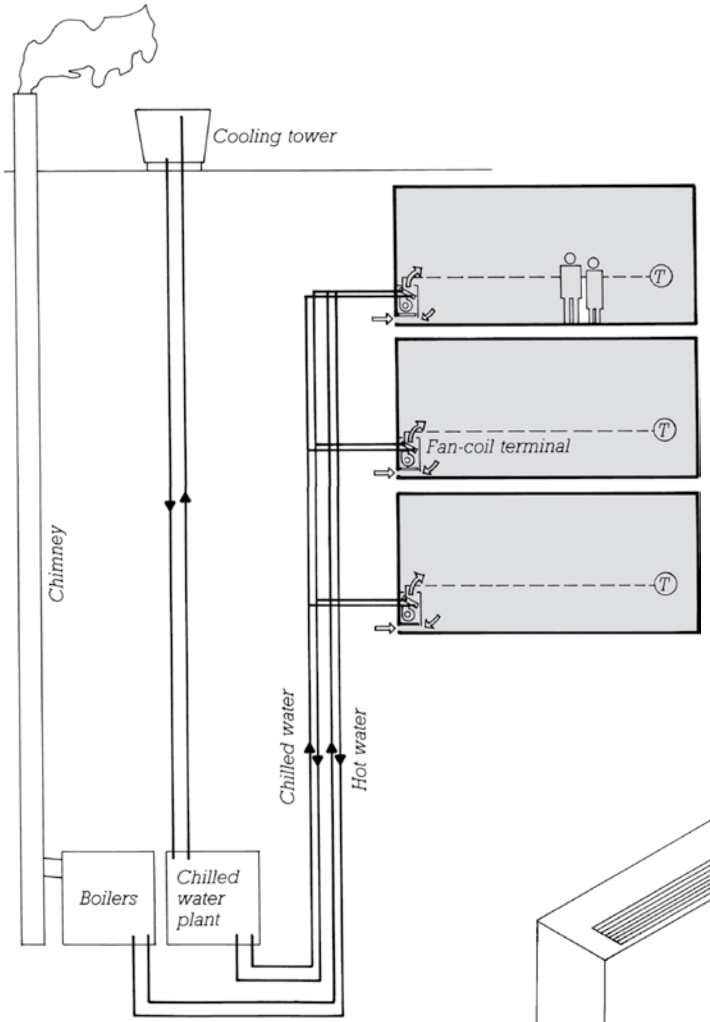
No fan rooms or ductwork spaces are required in the building. The temperature of each space is individually controlled. Installed costs are low.

Disadvantages

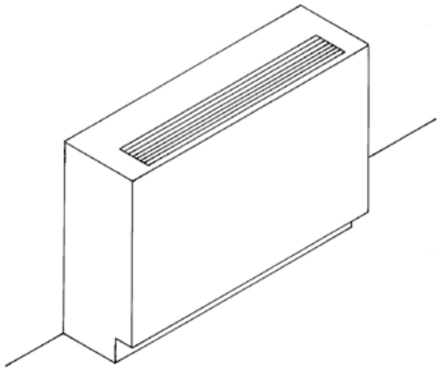
Humidity cannot be closely controlled. Fan-coil units may generate more noise than centralized air-handling systems. Maintenance of the units must take place within the occupied space of the building.

Major Components

The major components of a fan-coil terminal system are as follows: boilers and chimney, chilled water plant, cooling tower, vertical supply and return piping, horizontal supply and return piping, condensate drainage piping, fan-coil terminals, outside air grilles.



FAN-COIL TERMINAL SYSTEM



FAN-COIL TERMINAL

Sizing the Components

Fan-coil terminals are usually sized to fit beneath a window with heights from 25 to 28 in. (635 to 710 mm), depths from 9 to 12 in. (230 to 305 mm), and lengths from 30 to 84 in. (760 to 2130 mm). Other configurations include low-profile units as little as approximately 15 in. (380 mm) tall, horizontal units mounted under ceilings, or recessed units installed flush with walls or ceilings. For the dimensions of the other components of the system, see the chart on pages 216–219.

Variations

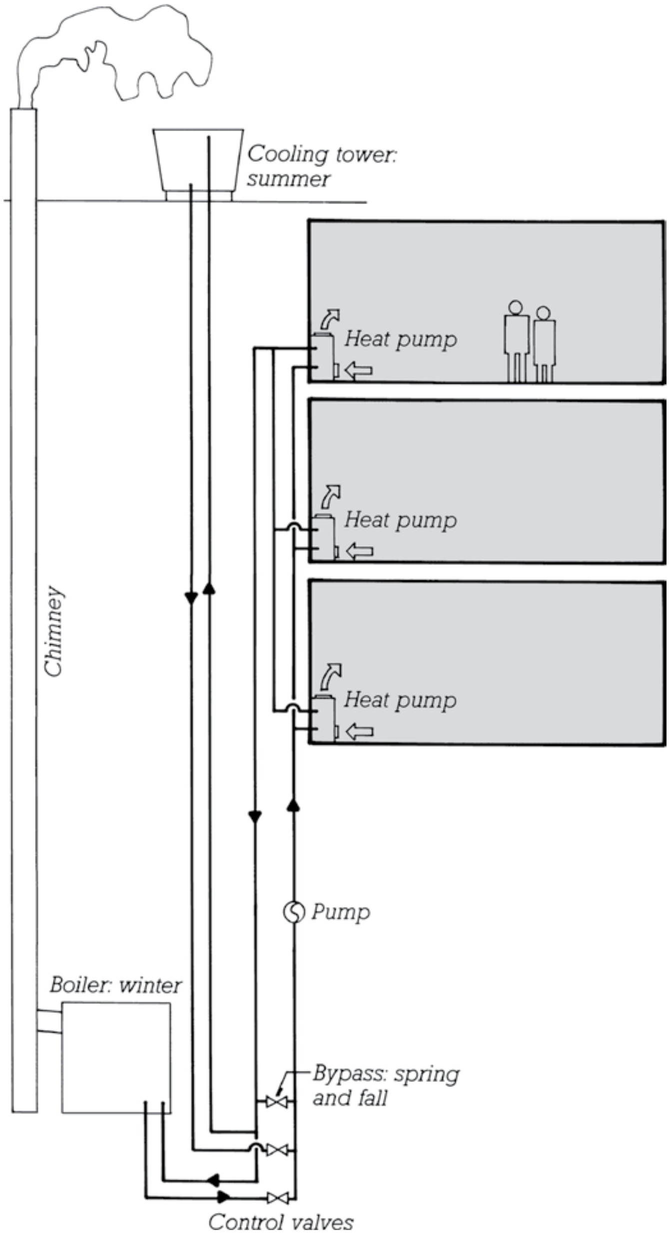
1. *Concealed fan-coil units* are mounted above suspended ceilings or in wall cavities. Ductwork carries conditioned air from the unit to diffusers in the occupied space. If needed, ductwork may also connect the unit fresh air inlet to a louvered opening in the exterior wall.

2. *Dedicated outdoor air systems* (page 165) can be used in combination with fan-coil units to satisfy requirements for fresh air supply and humidity control.

CENTRAL ALL-WATER SYSTEMS: CLOSED-LOOP HEAT PUMPS

Description

A water-to-air heat pump unit in each space provides heating, cooling, and fresh air. The water source for all the heat pumps in the building circulates in a closed loop of piping. Control valves allow the water to circulate through a cooling tower in the summer and a boiler in the winter, and to bypass both the boiler and the cooling tower in spring and fall and at any other time when the heating and cooling needs of the various rooms in the building balance one another.



CLOSED-LOOP HEAT PUMP SYSTEM

Typical Applications

This system is well suited for hotels containing chronically overheated areas (kitchens, laundry, assembly rooms, restaurants).

Advantages

This is an efficient system in which heat extracted from overheated areas can be used to heat underheated areas.

Disadvantages

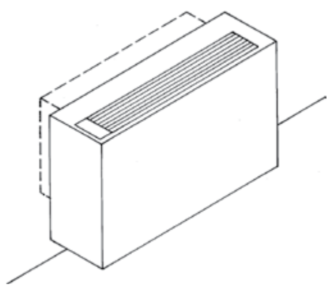
This is an expensive system to install, and careful economic analysis is needed to determine if the high installation costs can be balanced by energy savings. The heat pumps require that much of the routine maintenance take place in the occupied spaces. Humidity cannot be closely controlled.

Major Components

Heat pump units, boiler room, and cooling tower are the major components of the system.

Sizing the Components

The heat pumps may be located above a dropped ceiling over the bathroom and dressing areas in hotel rooms or below windows. A typical under-window heat pump unit is approximately 30 in. (760 mm) high, 12 in. (305 mm) deep, and 60 in. (1525 mm) long. An above-ceiling unit has approximately the same dimensions, with the 12-in. (305-mm) dimension vertical. For the dimensions of the other components of the system, see the chart on pages 216–219.



HEAT PUMP

CENTRAL ALL-WATER SYSTEMS: HYDRONIC CONVECTORS

Description

Hot water (or sometimes steam) from the boiler room is circulated through fin-tube convectors consisting of horizontal pipes with closely spaced vertical fins mounted inside a simple metal enclosure. The heated fins, working by convection, draw cool room air into the enclosure from below, heat it, and discharge it out the top. Thermostats manage temperatures by adjusting the flow of water in the hydronic piping.

Typical Applications

Hydronic convectors are used alone in buildings where cooling is not required and ventilation is provided by other means. Or they may be used as a supplemental source of heat in combination with other systems, for example to provide supplementary heating to perimeter floor areas where heat loss occurs through the exterior wall.

Advantages

Hydronic convectors are economical to install and operate.

Disadvantages

Cooling, humidity control, and ventilation must be provided by other means.

Major Components

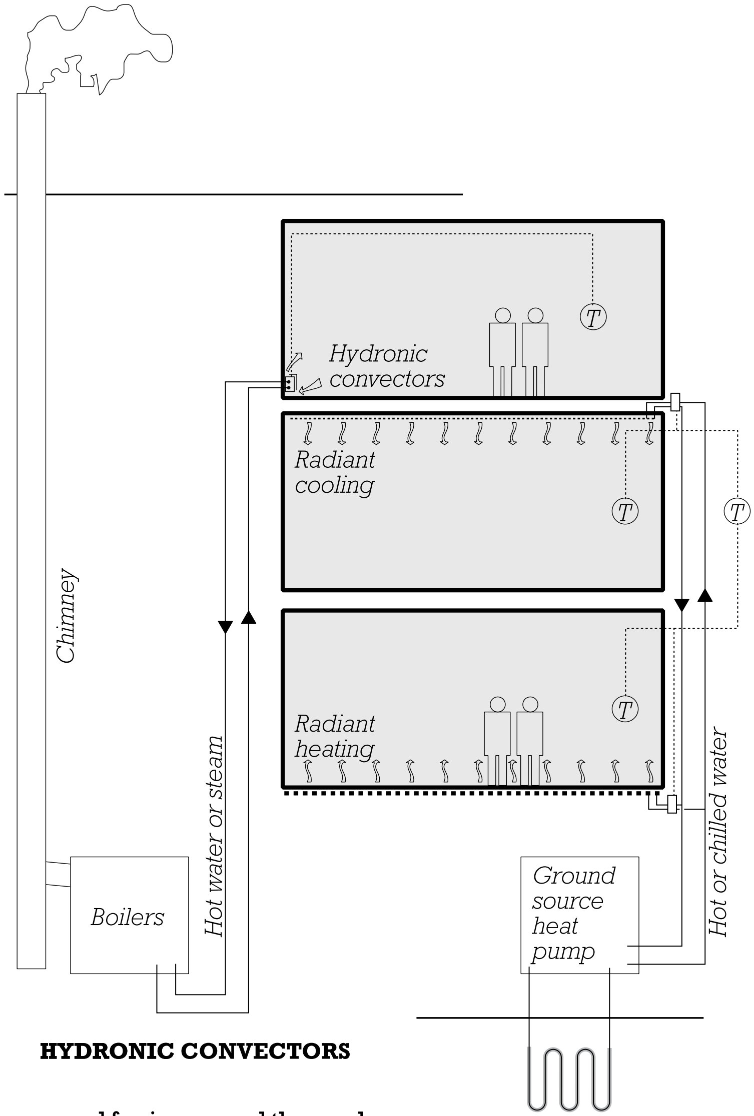
The major components of hydronic convector systems are as follows: boilers and chimney, vertical supply and return piping, horizontal supply and return piping, and convectors.

Sizing the Components

Hydronic convectors run continuously around the perimeter of a building. The smallest are about 5 in. (127 mm) square in cross section and are mounted at least 4 in. (100 mm) above the floor. Larger units, with enclosures up to 28 in. (710 mm) high and 6 in. (152 mm) deep, are used for improved thermal performance. Convectors are also available as cabinet units, either surface-mounted or recessed. For the dimensions of the other components of a hydronic heating system, see the chart on pages 216–217.

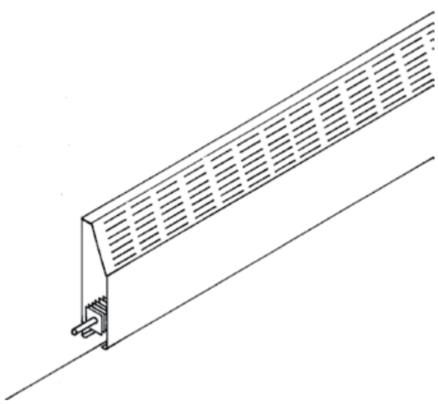
Variations

1. *Fan-forced unit heaters* are metal cabinets containing a hot-water coil and an electric fan to circulate air across the coil. They may be recessed in a wall, mounted on the surface of a wall, or suspended from the ceiling. Each cabinet unit may contain its own thermostat, allowing a high degree of individual control of heat output.



HYDRONIC CONVECTORS

HYDRONIC RADIANT HEATING AND COOLING



FIN-TUBE CONVECTOR

CENTRAL ALL-WATER SYSTEMS: HYDRONIC RADIANT HEATING AND COOLING

Description

Hot or chilled water is circulated through piping embedded in floors, walls, ceilings, or suspended panels, raising or lowering the temperature of these surfaces (see diagram, facing page). In turn, the thermal environment of the space is altered by radiant exchange of heat energy between these surfaces and occupants within the space: When the radiant surfaces are cooler than the ambient temperature, occupants will be cooled as they radiate heat to these surfaces. When the surfaces are warmer than the ambient temperature, occupants will be warmed as the surfaces radiate heat to them. In addition, convective thermal transfer can occur as air close to the radiant surfaces is heated or cooled and rises or falls. Temperature of the radiant surfaces is moderated by controlling the flow of water through the piping. Data from temperature sensors inside and outside the building is used to determine the appropriate flows.

Typical Applications

Radiant heating and cooling systems are well suited to spaces with high ceilings—for example, churches, large halls, industrial buildings, or sports facilities—where it would otherwise be expensive and difficult to control the temperature of the large air volumes. They are a good choice for spaces with high rates of air infiltration, such as loading docks, for similar reasons. In conventional low-ceiling spaces such as commercial offices, radiant heating and cooling can provide greater comfort and reduce energy costs, in comparison to many all-air systems.

Radiant heating located in floors benefits from convective heat exchange as warmed air close to the floor rises. Similarly, radiant cooling in ceilings benefits from convection as cooled air descends. However, neither system need be limited to only these orientations. For example, in spaces where floors receive large direct solar gains, radiant floor cooling can maintain comfortable temperatures at the floor level while efficiently removing the heat gains from the space.

Advantages

Radiant cooling and heating systems provide greater occupant comfort and operate more efficiently than all-air systems. Hydronic radiant systems have low maintenance costs, and the maintenance that does takes place occurs outside of occupied areas. Low-mass systems (see *Variations*, following) have quick response times to temperature changes. High-mass systems can shift cooling or heating to utility off-peak times when energy costs are lower. Because hydronic radiant systems use water that is closer to room temperature than other all-water systems, they work well with renewable or efficient energy sources such as heat pumps, geothermal exchange, or solar hot water.

Disadvantages

Humidity control and fresh air must be provided by other means, such as a dedicated outdoor air system (see page 165). With radiant cooling, temperatures must be carefully controlled to avoid condensation on cooled surfaces, especially in humid climates. For effective radiant heat exchange, heated or cooled surfaces must not be covered with high thermal resistance materials or furnishings, for example, thick carpet over heated floors.

Major Components

The major components of radiant cooling and heating systems are: sources of hot and/or chilled water, vertical supply and return piping, horizontal supply and return piping, and hydronic piping within the radiant surfaces.

Sizing the Components

The hydronic piping used to heat and cool radiant surfaces, typically ½ to ¾ in. (13 to 19 mm) in diameter, is hidden from view and normally has no impact on occupied space. It may be cast into concrete slabs or floor toppings, or built into various other floor or ceiling assemblies. Thin mats consisting of closely spaced *capillary tubes*, only roughly 3⁄16 in. (5 mm) in diameter, can be embedded in plaster or other thin finishes.

Variations

1. *Low-mass radiant systems*, for example in wood floors, thin tile assemblies, or plaster walls and ceilings, respond relatively quickly to changes in heating or cooling loads within the occupied space. Heating and cooling normally occurs during occupied hours.

2. *High-mass radiant systems* heat or cool thicker, more massive assemblies—usually concrete floor slabs—that can store heat energy for many hours. Heating or cooling of the slab can take place overnight, when utility energy charges are lower, while the radiant conditioning of the space carries on through daytime occupied hours.

3. *Phase-change materials* that change between liquid and solid states at close to room temperature can be added to low-mass assemblies to provide heat storage behavior more similar to that of high-mass systems.

LOCAL SYSTEMS: PACKAGED TERMINAL UNITS

TYPICAL DIMENSIONS OF PACKAGED TERMINAL UNITS

	Width	Depth	Height
Packaged terminal air conditioners	43″ (1100 mm)	14–20″ (360–510 mm)	16″ (410 mm)
Vertical terminal air conditioners	24″ (610 mm)	24″ (610 mm)	32–52″ (813–1321 mm)
Mini-split units, interior	32–50″ (813–1270 mm)	8–11″ (203–280 mm)	12–14″ (305–356 mm)
Mini-split units, exterior	30–38″ (762–965 mm)	12–16″ (305–406 mm)	22–32″ (559–813 mm)

Description

Packaged terminal air conditioners (*PTACs*) are factory preassembled and wholly self-contained units. Within each, an electric-powered compressor and evaporator coil provide cooling. Heating can be supplied with electric resistance coils or, for greater energy efficiency, by utilizing the compressor in a reversible cycle as a heat pump. A fan draws indoor air through a filter, adds a portion of outdoor air, passes the air across the cooling and heating coils, and blows it back into the room. Another fan circulates outdoor air independently through the unit to cool the condensing coils (and, in a heat pump cycle, to furnish heat to the evaporator coils). A control thermostat is built into each unit. The only service distribution to these units is an electric cable or conduit.

PTACs are placed along exterior walls, often below windows where heating and cooling loads are greatest. An opening in the wall with an exterior louver provides access to outside air.

Typical Applications

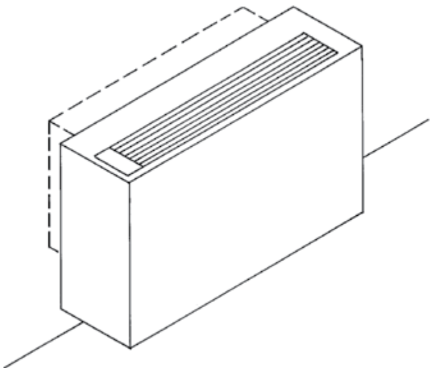
These units are suitable for apartments, dormitories, motels, hotels, office buildings, schools, and nursing homes.

Advantages

Units are readily available and easily installed. Initial costs are low. Each room has individual control of temperature. No building space is used for central equipment, ductwork, or piping. Operating costs may be lower than those for central systems in buildings in which not all spaces need to be heated or cooled all the time, such as motels.

Disadvantages

Maintenance must be carried out in the occupied spaces. Exposed units may be noisy or unsightly. Air distribution can be uneven. Wintertime humidification is not possible. Operating costs are high in areas with very cold winters and costly electricity.



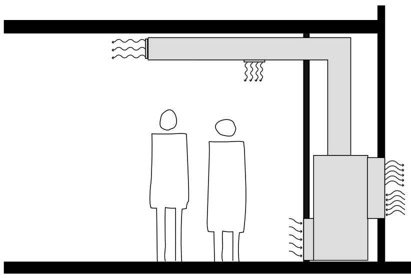
PACKAGED TERMINAL AIR CONDITIONER

Major Components

Components consist of simple, self-contained, packages.

Variations

1. *Vertical terminal air conditioners* are packaged units that are installed in closets or other concealed spaces against an exterior wall. Outdoor air is accessed through a louvered opening to the exterior. Inside return air is drawn through an interior grill and heated or cooled supply air is delivered by short runs of ductwork into the occupied space. Vertical units can operate at higher capacities than PTACs, and because they are concealed, they generate less noise within the occupied space.



VERTICAL TERMINAL AIR CONDITIONER

2. *Mini-split units* place the condenser and compressor portions of the unit completely outside the building. Insulated refrigerant piping connects the exterior portion to an interior component with evaporator coil and fan. Moving the compressor outside the building increases energy efficiency, reduces interior noise, and permits the interior portion to be mounted on any wall or the ceiling. Mini-split units cannot supply fresh air to the occupied interior. For more information about split-packaged systems, see pages 192–194.

2
CONFIGURING AND SIZING MECHANICAL AND ELECTRICAL SERVICES FOR LARGE BUILDINGS

This chapter will help you lay out the necessary spaces for mechanical and electrical equipment in a preliminary design for a large building.

MAJOR EQUIPMENT SPACES FOR LARGE BUILDINGS

The major equipment spaces for a large building are discussed in alphabetical order on the pages that follow.

BOILER ROOM AND CHIMNEY

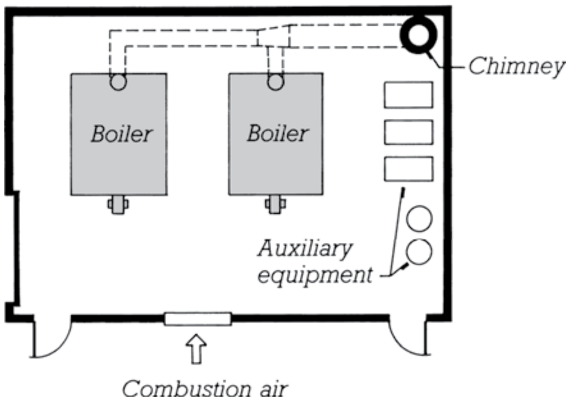
The boiler room produces hot water or, less commonly, steam to heat the building's spaces and its domestic water. Sometimes steam is also used to power absorption chilling equipment. In larger buildings, the boiler room normally contains at least two boilers so that one remains in service when the other is being cleaned or repaired. All boilers are connected to a single chimney. The boiler room may be placed anywhere in a building, including in a basement, a mechanical room on grade, a mechanical floor, or the roof. It should be on an outside wall because it needs an intake grille for combustion air and a door or removable panel to allow for equipment removal and replacement. Because of the noise and heat given off, a boiler room should be placed below or adjacent to areas such as loading docks and lobbies that will not be adversely affected. It is helpful to locate the boiler room next to the chilled water plant, and the two facilities are often combined in a single room. Hot water supply and return pipes run from the boilers through vertical shafts to reach the other floors of the building.

Boilers and their associated equipment create heavy floor loadings that need to be taken into account when designing the supporting structure. Depending on the size of the boilers, building codes may require that boiler room enclosure be fire-resistance rated or that the room be sprinklered.

Boilers may be fueled by gas, electricity, or oil. Electric boilers, which generally are economical only in areas where electricity costs are very low, eliminate the need for combustion air inlets and a chimney. For oil-fired boilers, typically at least a 2-week supply of fuel is stored in tanks in or near the building. Fuel tank filler pipes must be accessible to oil delivery vehicles. For underground storage, specially durable and corrosion-resistant tanks are used. When inside the building, tanks are located in spaces with natural ventilation, designed so that if the tank fails, oil will be contained within the space and not escape into other parts of the building. A basement location on an outside wall is preferred. Oil for a boiler on an upper floor of a building is pumped up a shaft through a pipe from the tanks below.

An approximate floor area for a boiler room may be determined using the chart on pages 216–217. In larger buildings, a long, narrow room is usually preferable to a square one. The ceiling height of a boiler room varies from a minimum of 12 ft (3660 mm) for a building of moderate size to a maximum of 16 ft (4880 mm) for a large building.

The size of the chimney that is associated with fuel-burning boilers varies with the type of fuel, the height of the chimney, the type of draft (natural, forced, or induced) that is employed, and other factors. For preliminary design purposes, allow a floor area of 2 ft × 2 ft (610 mm square) for a chimney in a very small building and 6 ft × 6 ft (1830 mm square) in a very large building, interpolating between these extremes for buildings of intermediate size. Keep in mind that the chimney runs through every floor of the building above the boiler room.



TYPICAL LAYOUT OF A BOILER ROOM

CHILLED WATER PLANT

The chilled water plant produces cold water used for cooling the building. The chillers are fueled by electricity, gas, or steam. The chillers give off heat, noise, and vibration, and should not be located near spaces they will adversely affect. They may be placed anywhere in the building from basement to roof, but they are heavy and require deeper-than-normal structural members for support. An outside wall location is desirable to allow for the necessary ventilation and maintenance access. Ideally, the chilled water plant should be adjacent to the boiler room. The two are often housed in the same room in buildings of moderate size. Supply and return pipes run from the chilled water pumps to the fan rooms, terminals, or other equipment that they serve. Condenser water supply and return pipes run between the chillers and the cooling towers.

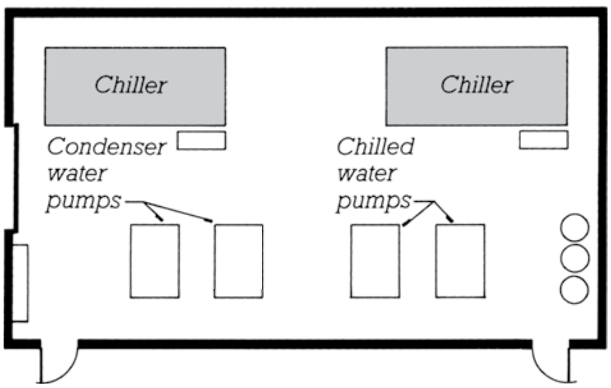
An approximate floor area for a chilled water plant may be determined using the chart on pages 216–217. In larger buildings, a long, narrow room is usually preferable to a square one. The ceiling height of a chilled water plant varies from a minimum of 12 ft (3660 mm) for a building of moderate size to a maximum of 16 ft (4880 mm) for a very large building.

COOLING TOWERS

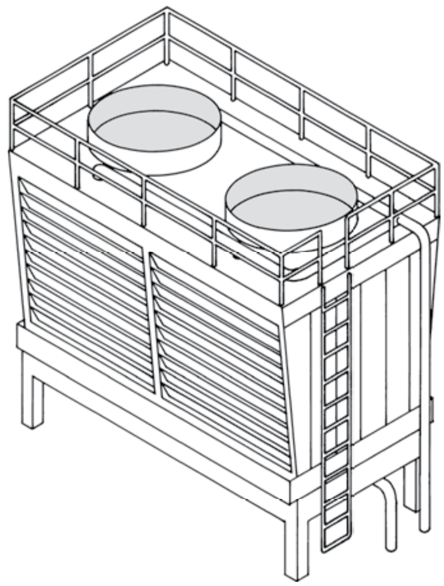
Cooling towers extract heat from the water that is used to cool the condenser coils of the chilled water plant. In effect, the cooling towers are the mechanism by which the heat removed from a building by the air conditioning system is dissipated into the atmosphere. Most cooling towers are "wet," meaning that the hot water from the condensers splashes down through the tower, giving off heat by evaporation and convection to a stream of air that is forced through the tower by fans. The cooled water is collected in a pan at the bottom of the tower and circulated back to the chillers.

The size and number of cooling towers are related to the cooling requirements of the building. Cooling towers may be located on the ground if they are at least 100 ft (30 m) from any building or parking lot to avoid property damage and unhealthful conditions from the splash, fog, and microorganisms given off by the towers. An alternate location is the roof of the building, but because of the noise and vibration they generate, the towers should be isolated acoustically from the frame of the building, and noise-sensitive areas such as auditoriums and meeting rooms should not be located directly below them. Rooftop cooling towers must also be located well away from windows and fresh air louvers.

A preliminary estimate of the roof or ground area occupied by cooling towers may be obtained from the chart on pages 216–217. Cooling towers range between 13 and 40 ft (4 and 12 m) in height; the height for a given building can be estimated by interpolating between these two extremes. The towers usually have a 4-ft (1.2-m) crawlspace beneath. For free airflow, they should be located one full width apart and at least 10 to 15 ft (3 to 5 m) from any screen wall or parapet wall unless the wall has very large louvers at the base to allow for intake air.



TYPICAL LAYOUT OF A CHILLED WATER PLANT



COOLING TOWER

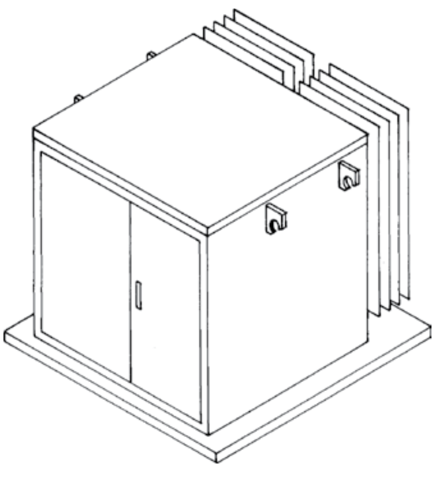
ELECTRICAL SERVICE ENTRANCE, TRANSFORMERS, SWITCHGEAR, AND EMERGENCY/ STANDBY POWER

Every building has an electrical transformer or transformers, a meter or meters, and a panel or switchgear that distributes the power to the interior wiring that services the building. The locations and sizes of these elements vary considerably, depending on the size and purpose of the building, the type of electric service provided by the local utility, the practices of the electric utility company, local codes, and other factors.

For reasons of efficiency, electric utilities transmit electricity at high voltages. Transformers reduce this to lower voltages that can be utilized directly in the building—typically 120/208 volts or 115/230 volts in wall and floor receptacles, and up to 480/277 volts for some types of machinery and lighting fixtures. A commercial building of up to 25,000 sq ft (2500 m^2) or a residential building of up to twice this size will most often buy its electricity at these lower voltages. For buildings in this size range, the transformer is provided by the utility company and may be mounted overhead on a transmission pole, on the ground (especially where transmission lines are underground), or, in some dense urban situations, in a nearby building or underground vault. A meter or meters belonging to the utility company are installed on or in the building where the service wires enter, and distribution within is usually by means of panels of circuit breakers that are located in an adjacent utility space or a small electrical closet.

Owners of larger buildings sometimes prefer to buy electricity at these lower voltages, but they can obtain energy more economically by providing their own transformers and purchasing electricity at the higher transmission voltage. One typical pattern is to bring electricity to the building at 13,800 volts and then to step down to 480/277 volts with a large primary transformer or transformers at the service entrance. The 277-volt electricity is used directly in many types of commercial and industrial lighting, and at 480 volts, electricity can be distributed efficiently to electrical closets in various parts of the building. Each electrical closet houses one or more small secondary transformers to step down from 480 volts to the lower voltages needed for convenience receptacles and machinery.

Primary transformers may be located either outside or inside the building. Where space is available, an outdoor transformer mounted on a ground-level concrete pad is preferred to an indoor transformer, because it is less expensive, cools better, is easier to service, transmits less noise to the building, and is safer against fire. Some common dimensions of pad-mounted transformers are shown in the upper table on the facing page. A transformer of this type does not need to be fenced except for visual concealment, in which case there must be a clear space of 4 ft (1.2 m) all around the pad for ventilation and servicing. The pad should be within 30 ft (9 m) of a service road and requires a clear service lane 6 ft (1.83 m) wide between the transformer and the road. Multiple outdoor transformers are often used to serve larger buildings and are usually placed at intervals around the perimeter of the building to supply electricity as close as possible to its point of final use.



PAD-MOUNTED TRANSFORMER

In a dense urban setting, or where the building owner finds outdoor placement objectionable, the primary transformer or transformers must be located within the building. Oil-filled transformers of the type the utility company provides for large buildings must be placed in a transformer vault, with fire rated enclosure and two exits. In a few large cities, it is customary to place the transformer vault under the sidewalk, covered with metal grating for ventilation. Dry-type transformers of the kind usually bought by owners of small and medium-sized buildings do not need a vault. They may be placed in the main electric room. The transformer vault or main electric room is often placed in the basement or on the ground floor but may be located on higher floors. Primary transformers are very heavy and require a heavier, deeper supporting structure than the rest of the building.

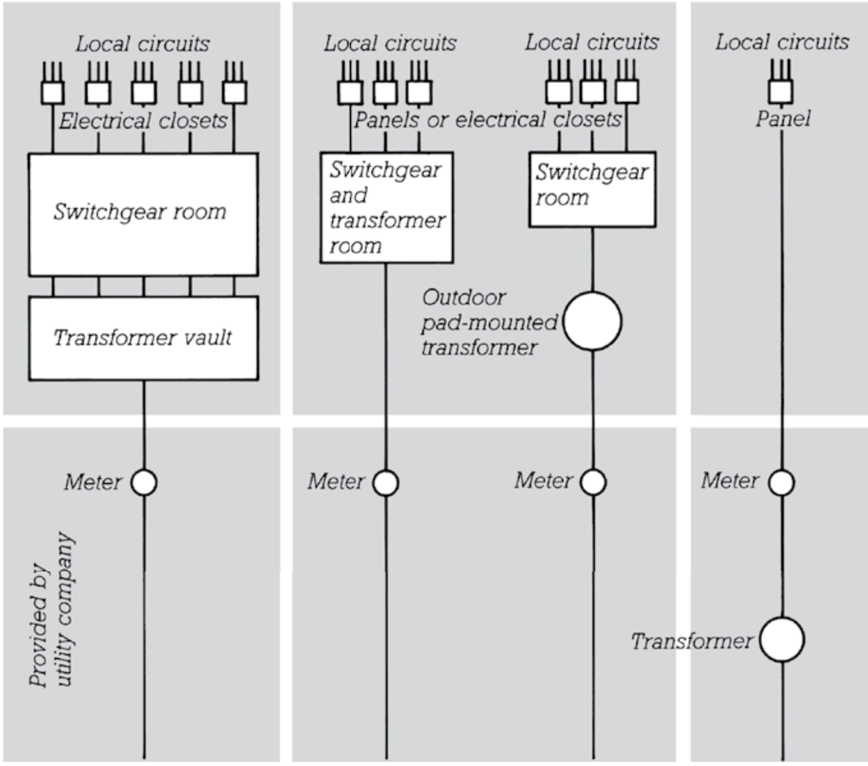
In buildings with dry-type transformers, the switchgear, consisting of disconnect switches, secondary switches, fuses, and circuit breakers, may be housed in the same enclosure with the transformers in a configuration known as a *unit substation*. In large buildings with oil-filled transformers, the switchgear is located in a room adjacent to the transformer vault.

MAJOR EQUIPMENT SPACES FOR LARGE BUILDINGS

Transformers and switchgear must be ventilated because they give off large quantities of heat. It is best to locate them against an outside wall so that high and low convective ventilation openings can be provided. If this is not possible, ventilation can be accomplished by ductwork and fans connected to outdoor air louvers. Access panels or doors must be provided for servicing and replacing switchgear and transformers. Some examples of sizes of transformer vaults and switchgear rooms are given in the lower table on this page.

Several large conductors run from the transformers to the switchgear and from the switchgear to the vertical and horizontal distribution components that feed electrical closets throughout the building. For information on vertical distribution and electrical closets, see page 199. For information on horizontal distribution, see pages 211–214.

Where it is important to maintain a continuous supply of electrical power, service may be brought to a building from two or more independent electric substations and possibly routed through separate transformers and switchgear at the building site. In this way, the building is less vulnerable to power outages resulting from a single point of failure in the upstream supply.



LARGE BUILDINGS **MEDIUM-SIZED BUILDINGS: TWO ALTERNATIVES** **SMALL BUILDINGS**

TYPICAL DIMENSIONS OF PAD-MOUNTED TRANSFORMERS

Floor Area of Commercial Building	Number of Residential Units	Pad Size
18,000 ft² (1,700 m²)	50	52 × 44 in. (1.3 × 1.2 m)
60,000 ft² (5,700 m²)	160	52 × 50 in. (1.3 × 1.3 m)
180,000 ft² (17,000 m²)	—	96 × 96 in. (2.4 × 24. m)

TYPICAL SIZES OF TRANSFORMER VAULTS AND SWITCHGEAR ROOMS

Floor Area of Commercial Building	Floor Area of Residential Building	Size of Combined Room for Transformers and Switchgear	Size of Transformer Vault	Size of Switchgear Room
150,000 ft² (15,000 m²)	300,000 ft² (30,000 m²)	30 × 30 × 11 ft (9.14 × 9.14 × 2.44 m)		
100,000 ft² (10,000 m²)	200,000 ft² (20,000 m²)		20 × 10 × 11 ft (6.0 × 6.0 × 3.35 m)	30 × 20 × 11 ft (9.0 × 6.0 × 3.35 m)
300,000 ft² (30,000 m²)	600,000 ft² (60,000 m²)		20 × 40 × 11 ft (6.0 × 12.0 × 3.35 m)	30 × 41 × 11 ft (9.0 × 12.0 × 3.35 m)
1,000,000 ft² (100,000 m²)	2,000,000 ft² (200,000 m²)		20 × 80 × 11 ft (6.0 × 24.0 × 3.35 m)	30 × 80 × 11 ft (9.0 × 24.0 × 3.35 m)

In many buildings, onsite equipment capable of generating power in the event of an interruption in normal electrical service is also required. Such equipment can provide *emergency power* for building systems essential to life safety—such as assembly area lighting, fire detection, alarm systems, fire pumps, elevators, and emergency communications—or *standby power* for less essential services. The equipment consists of one or more electrical generators driven by engines fueled with natural gas, propane gas, diesel oil, or gasoline. In the case of all but natural gas, onsite fuel storage is required. During testing and operation, large quantities of air for combustion and cooling are required, and exhaust gases, noise, and vibration are emitted. The best location for power generating equipment is on the ground outside the building, near the switchgear room. Engine-generator sets in prefabricated weather-resistant housings are available for this purpose. The next best location is on the roof of the building. Alternatively, this equipment may be located inside the building on an exterior wall, as far as possible from occupied areas of the building and within a fire-resistance-rated enclosure. Typical dimensions for the housing or room to accommodate an emergency power supply for an average commercial building of up to 150,000 sq ft (14,000 m^2) are 12 ft (3.7 m) wide and 18 ft (5.5 m) long. A space of the same width, 22-ft (6.7-m) long, will accommodate the supply for a building of up to 400,000 sq ft (37,000 m^2). Where additional standby power is required, space requirements will be greater.

There is a loss of power for a period of up to 10 seconds between the time a power interruption occurs and the onsite generator takes over. Where this brief interruption is unacceptable, such as in buildings with specialized medical equipment, computers, communications equipment, certain types of lighting, or an extraordinary need for security, a battery-powered uninterruptible power supply (UPS) provides electricity during this transition. The UPS requires a room for batteries and an adjacent room for specialized circuit breakers and electronic controls. These should be located close to the area that utilizes the UPS power. A typical computer room of 10,000 sq ft (1000 m^2) requires an outside-ventilated battery room of 500 sq ft (47 m^2) and a room of 200 sq ft (19 m^2) for electronic equipment. Both of these rooms require air conditioning. Depending on the power capacity, the enclosure of the UPS equipment may be required to be fire-resistance rated.

ENERGY STORAGE

Adding mass *thermal energy storage* can improve the energy efficiency of building heating and cooling systems. Energy storage smooths out the peaks of heating and cooling demand. This allows smaller-capacity, more efficient equipment to be used. It allows the redistribution of excess heat from one area of a building to other areas where added heat is needed, or the storage of excess heat until it can be used at a later time. It allows heating and cooling equipment to do more work at night when demands on the utility grid and utility rates are lower and when cooling equipment can operate more efficiently in the cooler night air.

Thermal energy can be stored in large tanks of water or ice located within the building. Because the melting and freezing of ice adds to its thermal capacity, ice tanks can be smaller than water tanks providing equal amounts of storage. Energy storage tanks should be located close to the boiler rooms and chiller plants they serve. Because the tanks are large and heavy, mechanical spaces at or below grade can be good choices when available. In addition to providing energy storage, the stored water can be made available to the fire sprinkler system in the event of a building fire. Storage tanks themselves can even serve as the suspended mass in tall building tuned mass dampers (see page 54).

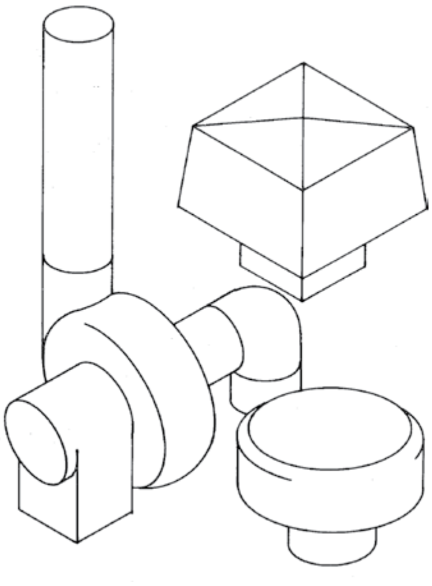
Use the table below for the preliminary sizing of water and ice energy storage tanks. Additional space should be provided for the related controls, pumps, heat exchangers, and in the case of ice storage, refrigeration equipment, that are part of the system.

PRELIMINARY SIZING OF ENERGY STORAGE TANKS

Storage Medium	Tank Height	Tank Floor Area Required for Each 1000 sf (93 m^2) of Conditioned Space
Water	8 ft (2.4 m)	15 ft^2 (1.4 m^2)
Ice	8 ft (2.4 m)	3.8 ft^2 (0.35 m^2)

EXHAUST FANS

Exhaust fans draw air constantly from toilet rooms, locker rooms, bathrooms, janitor closets, storage rooms, corridors, and kitchens and deliver it to the outdoors to keep the air fresh in these spaces. Exhaust fans are also used to evacuate air from laboratory fume hoods and many industrial processes. The fans are usually housed in small mushroom ventilators on the roof and are connected to the spaces they serve by ducts that run through the vertical shafts in the cores of the building. It is difficult to generalize about the sizes of exhaust ducts and fans; they tend not to be extremely large, so it is usually sufficient to allow a small amount of shaft space and roof space that can later be adjusted in consultation with the mechanical engineer.



EXHAUST FANS

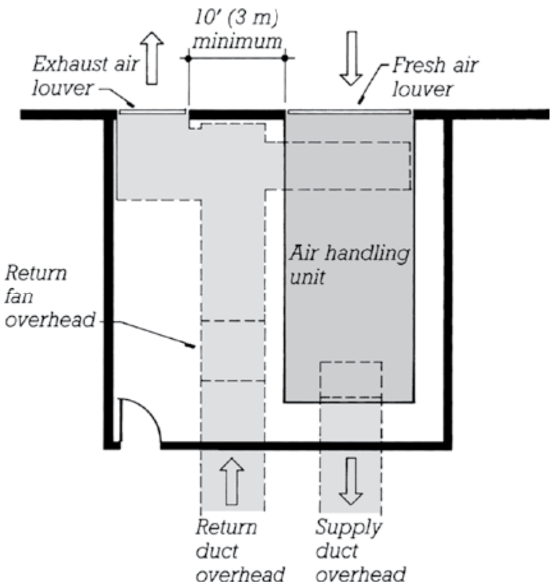
FAN ROOMS AND OUTDOOR AIR LOUVERS

In all-air and air and water heating and cooling systems, one or more air handling units in a fan room circulate conditioned air through ducts to the occupied spaces of the building. A return fan draws air from the occupied spaces back to the fan room through return ducts. In the fan room, some portion of the return air may be recirculated into the supply air stream, or, some form of energy recovery may be implemented between the two air streams before the return air is exhausted to the exterior. Frequently, supply air fans are run at slightly higher speeds than return fans, so as to slightly pressurize the building interior in relation to the exterior and minimize the unintended infiltration of outside, unconditioned air. (For example diagrams of these processes, see pages 174–178.)

Fan rooms may be located anywhere in the building; they are supplied with hot and chilled water through insulated pipes from the boiler room and the chilled water plant. A floor plan of a typical fan room is shown below. If only a single fan room is used, it may be placed in the basement, on the ground floor, on the roof, or on any intermediate floor, as close to the vertical distribution shafts as possible. It is most convenient to locate this room near an outside wall, but if an outside wall location is not possible, ducts to the outdoors are used to convey fresh air and exhaust air to and from the air handlers. These ducts may run horizontally, above a ceiling, or vertically, in a shaft.

Many buildings have multiple fan rooms (see the diagrams next page). Separate fan rooms allow different heating and cooling zones to be supplied individually. Multiple fan rooms may reduce the distance that ductwork must travel horizontally. This in turn may reduce the depth of horizontal ductwork, reduce the depth of space needed above ceilings, and reduce building floor-to-floor heights. Fan rooms located on every floor eliminate the large vertical chases otherwise needed to distribute air between floors. Separate fan rooms for separate tenants allow heating and cooling costs to be billed individually to each.

In tall buildings, it is common to dedicate entire floors to space for fan rooms, other equipment, and services. Typically these floors



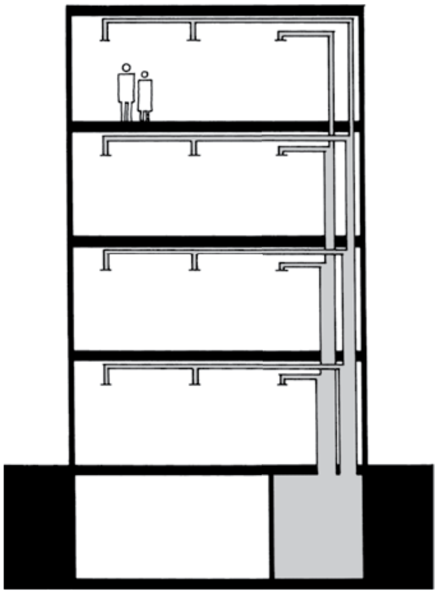
TYPICAL LAYOUT OF FAN ROOM

are about twice as tall as occupied floors. In office buildings intermediate mechanical floors occur roughly every 20 stories. In residential towers, such floors occur roughly every 30 stories.

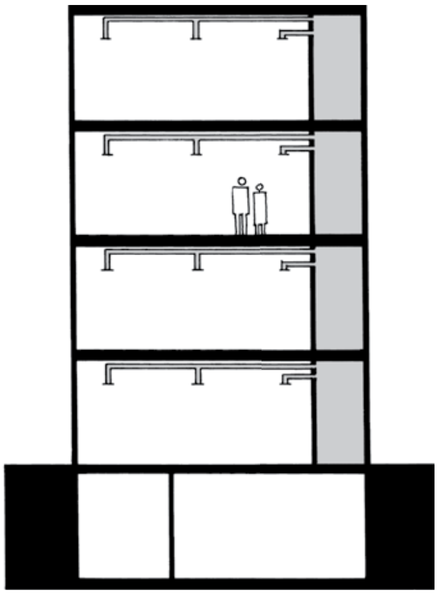
Fan room equipment is often heavy enough to require stronger structural support than the surrounding areas of the building. Noise-sensitive areas such as meeting rooms and auditoriums should not be located adjacent to fan rooms, which produce vibration and noise.

The fresh air and exhaust air louvers associated with a fan room are noisy and create strong local air currents. They need to be located a minimum distance apart, usually at least 10 ft (3 m), on the exterior wall, so that the outgoing and incoming air do not mix. Louvers for small pieces of equipment such as fan-coil units are very small. With careful design work, they can be integrated unobtrusively into the fabric of the wall. Louvers for larger pieces of equipment grow progressively larger with the floor area each serves. They are large and conspicuous for central fans serving a number of floors and require special attention on the part of the architect.

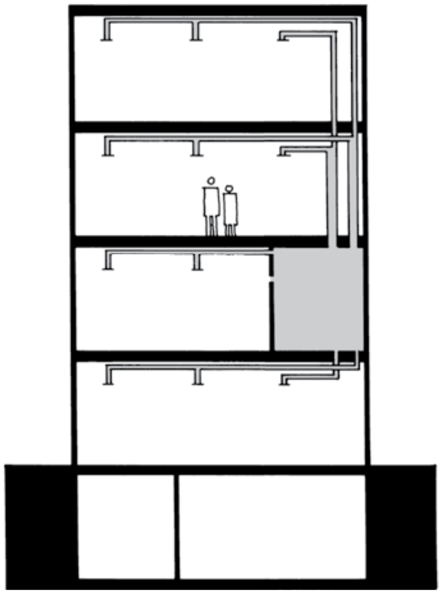
Use the graph on page 218 to determine the approximate sizes of outdoor louvers for preliminary design purposes. The same graph gives information on sizing fan rooms as a function of floor area served. Using this graph, one may quickly evaluate a number of schemes for air distribution, using one fan room or many, to determine the effect of each scheme on the space planning and the exterior appearance of the building.



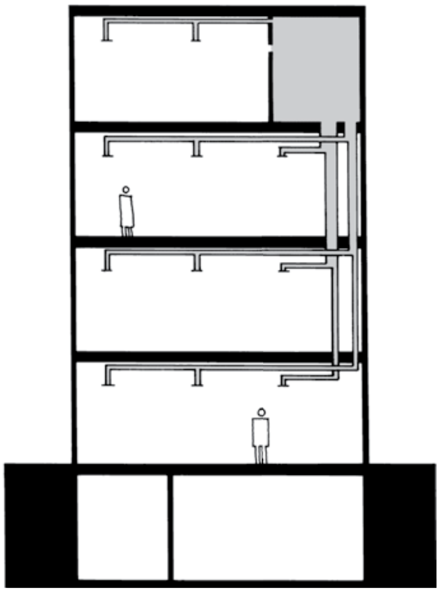
FAN ROOM IN A BASEMENT



FAN ROOM ON EACH FLOOR



FAN ROOM ON AN INTERMEDIATE FLOOR



FAN ROOM AT THE TOP OF A BUILDING

LOADING DOCK AND ASSOCIATED SPACES

Every large building needs at least a single loading dock and freight room for receiving and sending mail and major shipments, moving tenant furniture in and out, removing rubbish, and facilitating the servicing of mechanical and electrical equipment. The dock needs to be situated so that trucks may back up to it easily without obstructing traffic on the street. The freight room inside the dock area should open directly to the rubbish compactor and the freight elevators, and should be connected to the major mechanical equipment spaces and the mail room. It is often appropriate to locate the oil filler pipes next to the truck ramp that leads to the loading dock. If possible, the access doors to the major equipment spaces should also open to the dock or ramp area.

PACKAGED CENTRAL HEATING AND COOLING EQUIPMENT

Packaged central heating and cooling equipment may be single-packaged or split-packaged. *Single-packaged units* provide heating and cooling by combining the functions of a boiler room and chimney, a chilled water plant, and a fan room into a compact, rectangular, weatherproof unit that is specified, purchased, and installed as a single piece of equipment. Ductwork transports supply and return air between the exterior packaged unit and the spaces served within the building.

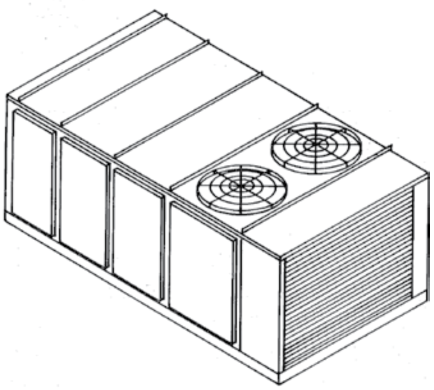
Split-packaged units are furnished in two parts: (1) outdoor packaged compressor and condensing coils and (2) an indoor packaged evaporator coils and circulating fan. The two parts are connected by insulated refrigerant tubing and control wiring. Ductwork delivers conditioned air from the evaporator package to the areas served. Split-packaged units cost slightly more than single-packaged units, but are more energy efficient because none of the ductwork is located outside the insulated shell of the building. Split systems cannot introduce fresh outside air into the building—where this is required, it must come from another system.

Variations on packaged systems include:

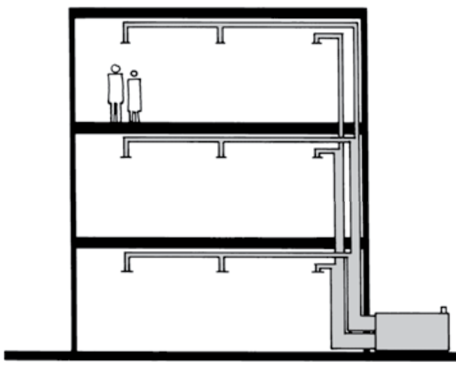
■ *Packaged heat pump units*, in which heating is provided by reversing the flow of refrigerant through the condenser and evaporator coils, rather than from a gas-fired furnace or electric resistance heating. In climates where outside temperatures rarely drop far below freezing, heat pump units can provide heating at much higher efficiencies than those that rely on gas or electric resistance heating.

■ *Ductless split-packaged systems* rely on one or more interconnected, interior evaporator packages located directly within the spaces they serve, eliminating the need for any ductwork.

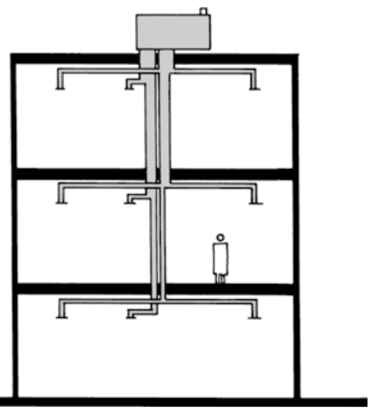
■ *Variable refrigerant flow (VRF) split-packaged systems* precisely control the flow of refrigerant to individual evaporator packages, allowing one system to serve multiple zones, even with highly disparate heating or cooling demands. VRF systems can operate at higher



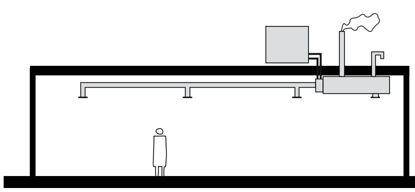
SINGLE-PACKAGED UNIT



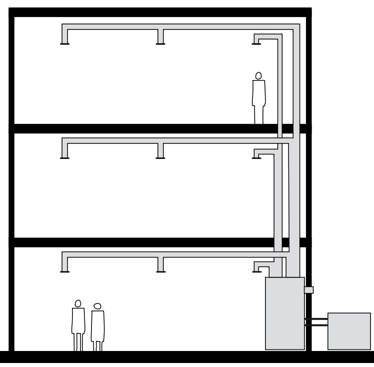
THROUGH-THE-WALL SINGLE-PACKAGED UNIT



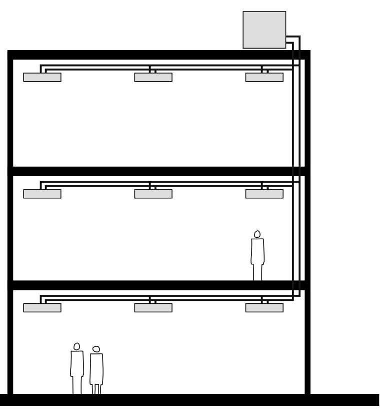
ROOFTOP SINGLE-PACKAGED UNIT



ROOFTOP SPLIT-PACKAGED UNIT



THROUGH-THE-WALL SPLIT-PACKAGED UNIT



DUCTLESS HEAT PUMP SPLIT-PACKAGED UNIT

TYPICAL DIMENSIONS OF SPLIT-PACKAGED COMPONENTS

Cooling Capacity in Tons (mcal/sec)		10 (35)	20 (70)	30 (106)	40 (141)	50 (176)
Outdoor Unit	Length	6′-4″ (1.93 m)	12′-11″ (3.94 m)	12′-11″ (3.94 m)	12′-11″ (3.94 m)	12′-11″ (3.94 m)
	Width	3′-8″ (1.12 m)	4′-0″ (1.22 m)	4′-10″ (1.47 m)	7′-1″ (2.16 m)	7′-1″ (2.16 m)
	Height	3′-4″ (1.02 m)	2′-4″ (0.71 m)	3′-2″ (0.97 m)	4′-9″ (1.45 m)	5′-8″ (1.73 m)
Indoor Ceiling-Suspended Unit	Length	8′-3″ (2.51 m)	7′-10″ (2.39 m)	9′-0″ (2.74 m)	9′-8″ (2.95 m)	9′-8″ (2.95 m)
	Width	5′-3″ (1.60 m)	6′-8″ (2.03 m)	7′-10″ (2.39 m)	10′-7″ (3.23 m)	10′-7″ (3.23 m)
	Height	2′-2″ (0.66 m)	2′-6″ (0.76 m)	3′-0″ (0.91 m)	3′-10″ (1.17 m)	3′-10″ (1.17 m)
Indoor Floor-Mounted Unit	Length	5′-3″ (1.60 m)	6′-8″ (2.03 m)	7′-10″ (2.39 m)	10′-7″ (3.23 m)	10′-7″ (3.23 m)
	Width	2′-2″ (0.66 m)	2′-6″ (0.76 m)	3′-0″ (0.91 m)	3′-10″ (1.17 m)	3′-10″ (1.17 m)
	Height	8′-3″ (2.51 m)	7′-10″ (2.39 m)	9′-0″ (2.74 m)	9′-8″ (2.95 m)	9′-8″ (2.95 m)

Use the chart on page 216 to estimate the required cooling capacity.

efficiencies and can deliver heating and cooling simultaneously to separate zones.

Packaged units, whether single or split, are fueled entirely by electricity or by a combination of electricity and gas. Packaged equipment is simple for the designer to select and specify and is easy to purchase and install because it is supplied as off-the-shelf units that need only external connections to fuel, electricity, control wiring, and air ducts. Packaged units are available in single-zone and multizone configurations in a variety of sizes to serve a wide range of demands for cooling and heating. They can be purchased as variable air volume (VAV) or constant air volume (CAV) systems (see pages 174–177).

Single-packaged units are located either on the roof or on concrete pads alongside the building. If alongside, the supply and return ducts are connected to the end of the unit and pass through the side wall of the building before branching out to the spaces inside. In a rooftop installation, the ducts pass through the bottom of the unit and into the building (see diagrams on previous page). The ducts from single-packaged units can serve low multistory buildings through vertical shafts that connect to above-ceiling branch ducts on each floor. Rooftop units may be placed at intervals to serve a building of any horizontal extent. The same is true of units located alongside the building, although the depth of the building is somewhat restricted by the maximum practical reach of the ducts. Using the chart on page 216, you may select a combination of unit size and numbers of units to serve any desired size and shape of building. For buildings taller than four or five stories, or for large buildings where only one central plant may be installed, conventional central equipment assembled from components must be used because of the relatively limited capacity range of packaged units.

The exterior condenser for a split-packaged unit is also located either on the building rooftop or on the ground next to the building, and is connected to the interior evaporator package by insulated refrigerant piping. Conditioned air from the evaporator is either discharged directly or carried through ducts to the spaces being served (see diagrams on previous page).

The table above will help to determine preliminary sizes for split-packaged equipment. For ducted systems, the inside package may be a horizontal unit that hangs from the roof structure or a vertical unit that stands on the floor. Inside packages for ductless systems may be exposed cabinets mounted under windows, on walls, or under ceilings, or they may be concealed and integrated into suspended ceilings.

SEWAGE EJECTOR PIT

If the lowest level of a building lies below the level of the sewer or septic tank, sewage is collected in an underfloor pit and pumped up to the sewer. The pit must lie beneath unobstructed floor space so that it can be inspected and serviced through a removable cover.

CENTRAL TELECOMMUNICATIONS ROOM

A central room for telephone and other communication systems should be located in the basement or on the ground floor as close to the telecommunications service entrance as possible. Where subsidiary telecommunications distribution rooms are stacked on floors above, this room should be located directly below these other rooms as well. Equipment needs in this room can vary significantly and are likely to change over time. For preliminary design purposes, the service entrance room should be no smaller than 65 sq ft (6 m^2), and may be 400 sq ft (40 m^2) or larger for a large commercial office building. The room should be free of plumbing, steam, or other piping. From this room, telecommunications wiring extends to distribution closets on each floor (see page 199).

WASTE COMPACTOR

A waste compactor is necessary in most large buildings and is often served by a vertical refuse chute from the floors above. The chute must be placed in a fire-resistance-rated enclosure and be provided with an automatic sprinkler head above the top opening. Some codes also require the provision of a fire-resistance-rated enclosed room outside the chute opening at each floor. Inside diameters of chutes range from 15 to 30 in. (380 to 760 mm), with 24 in. (610 mm) being a typical dimension.

The waste compactor should be located directly beneath the refuse chute and adjacent to the loading dock. The size and shape of the compactor itself vary widely with the manufacturer and the capacity of the unit. A compactor room of 60 sq ft (5.6 m^2) is sufficient for a small apartment building. A larger building will require 150 to 200 sq ft (14.0 to 18.6 m^2), and industrial waste compacting facilities can be much larger.

WATER PUMPS

Where the water service enters the building, a room is required to house the water meter and the sprinkler and standpipe valves.

SPACE REQUIREMENTS FOR WATER PUMPS

Domestic Water Pumps	
Area Served	**Room Dimensions**
Up to 200,000 ft^2 (Up to 18,600 m^2)	8′ × 12′ (2.44 × 3.66 m)
200,000 to 1,000,000 ft^2 (18,600 to 93,000 m^2)	16′ × 12′ (4.88 × 3.66 m)
Fire Pumps (assuming sprinklers)	
Area Served	**Room Dimensions**
Up to 100,000 ft^2 (Up to 93,000 m^2)	8′ × 12′ (2.44 × 3.66 m)
100,000 to 200,000 ft^2 (9300 to 18,600 m^2)	20′ × 12′ (6.1 × 3.66 m)
1,000,000 ft^2 (93,000 m^2)	30′ × 24′ (9.15 × 7.32 m)

In a building taller than three or four stories, a suction tank and a pair of water pumps are needed to boost the water pressure in the domestic water system. A similar pair of pumps is required for all but very small sprinkler systems. A chiller for drinking water and a heat exchanger to heat domestic hot water are often located in the same area. The following table will assist in determining the necessary floor areas for water pumps. The enclosures for fire pump rooms in high-rise buildings are often required to be fire-resistance rated. In tall buildings, fire codes frequently require the provision of a large gravity tank on the roof of the building to furnish a reserve of water in case of fire.

WORKROOMS, CONTROL ROOMS, AND OFFICES

Operating and maintenance personnel in large buildings need space in which to work. Offices should be provided for operating engineers and maintenance supervisors. A room is required to house the control console for a large-building heating and cooling system. Lockers and workrooms are needed for mechanics, plumbers, electricians, and custodial workers. Storage facilities should be provided near the loading dock and service elevator for tools, spare parts, and custodial equipment and supplies.

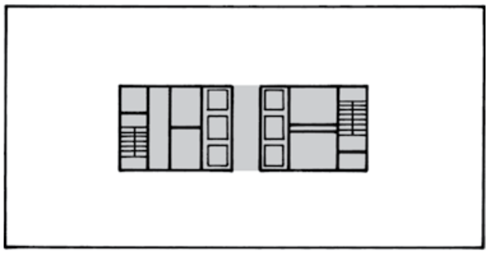
PLANNING SERVICE CORES

Spaces for the vertical distribution of mechanical and electrical services in a large building need to be planned simultaneously with other building elements that are vertically continuous or that occur in stacks—principally the structural columns, bearing walls, shear walls, and wind bracing; exit stairways; elevators and elevator lobbies; and rooms with plumbing: toilet rooms, bathrooms, kitchens, and janitor closets. These elements tend to coalesce into one or more core areas where the vertically continuous elements are concentrated into efficient, packaged blocks of floor space, leaving most of each floor open for maximum flexibility of layout.

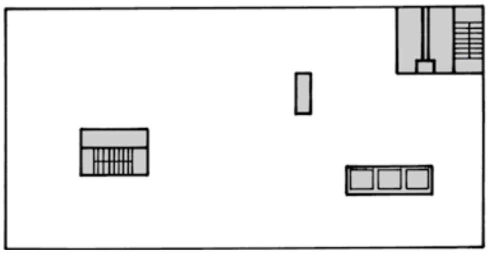
Different types of buildings call for different sorts of core arrangements. In high-rise office buildings, where a maximum amount of unobstructed, rentable area is the major criterion for floor layout, a single central core is almost universal. In low-rise commercial and institutional buildings, horizontal distances are often great enough that a single core would be inefficient, and vertical elements are divided into several cores of varied internal composition. These are likely to be located asymmetrically in response to the servicing and circulation patterns of the building. In a dormitory, apartment building, or hotel, a common pattern of vertical services features slender shafts sandwiched between pairs of living/sleeping units. Shafts next to the interior corridor carry the plumbing for the bathrooms and kitchens that back up to them. If the heating and cooling equipment for the units is located over the bathrooms and kitchens, the hot and chilled water piping and ductwork may share these same shafts. If the heating and cooling occurs along the outside walls, another set of shafts may be created between units around the perimeter of the building to serve this equipment.

Vertical distribution shafts need to connect directly with the major equipment spaces that feed them and the horizontal distribution lines they serve. The boiler room, chilled water plant, central fan room, exhaust fans, water pumps, sewage ejector, waste compactor, and cooling towers need to cluster closely around the vertical distribution shafts. The electric and telecommunications switchgear should not be far away. The electrical and telecommunications closets must stack up along the wiring shafts at each floor. The toilet rooms, bathrooms, kitchens, and janitor closets must back up to plumbing walls. Horizontal supply and return ducts need to join easily with the vertical ducts in the shafts, and horizontal piping for hot and chilled water distribution must branch off conveniently from the riser pipes.

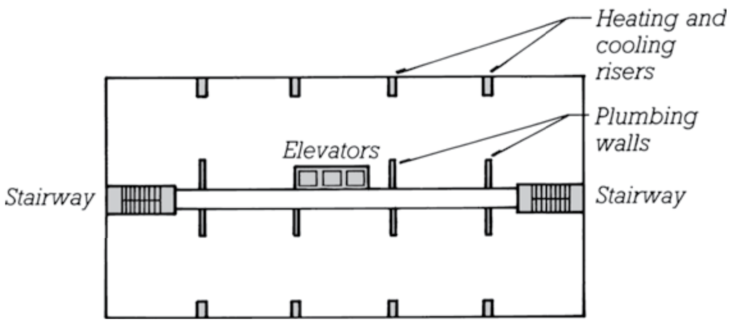
To protect against the rapid spread of smoke and fire between building floors, the enclosing walls of shafts of all types, including those for stairs, elevators, and building services, must almost always be fire-resistance rated—see pages 382–385 for more information.



HIGH-RISE OFFICE BUILDING: VERTICAL SERVICES IN A CONCENTRATED CORE



LOW-RISE BUILDING: VERTICAL SERVICES IN SCATTERED LOCATIONS



HOTEL OR APARTMENT BUILDING: VERTICAL SERVICES BETWEEN UNITS

LOCATING THE CORES IN THE BUILDING

A centrally located core leaves the daylit perimeter area of the building open for occupant use. It also works efficiently with a scheme that distributes services horizontally from one set of shafts, because it minimizes duct and pipe sizes. The central location can be undesirable, however, because it interrupts the open space of the floor. A core at one edge of the building does not have this problem, but it may not be able to incorporate exit stairways that are separated widely enough (see page 271), and it obstructs a portion of the daylit perimeter. Either of these core locations connects well to major equipment on the ground, the roof, and any intermediate mechanical floors.

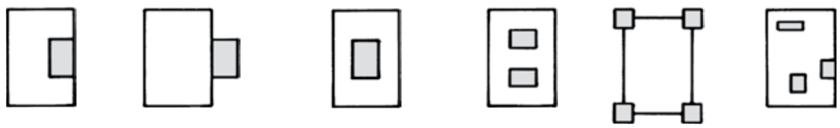
A core located in a corner, on the other hand, is undesirable because horizontal distribution lines from the core are long, exit stairways are too close together, and connections to major equipment are congested. Two or more corner cores used in combination can overcome some of these problems.

Multiple cores often work well, particularly in broad, low-rise buildings. Exit stairways can be widely separated and connected to a simple, clear system of corridors and elevators. Vertical risers for mechanical services can be located where they work best, minimizing the congestion of ducts and pipes at points of connection to horizontal networks.

Core locations may also be dictated in part by the structural scheme that provides lateral stability to the building. A large, centrally located core or two symmetrically placed cores can furnish ideal locations for wind and seismic bracing. A core at the edge of the building or a detached core cannot house all the bracing for the building because it is located asymmetrically with respect to one of the principal axes of the building (see page 42). Scattered cores and corner cores may not be large enough to develop the required depth of bracing elements.

The following chart summarizes some of the advantages and disadvantages of different options for core placement.

CHARACTERISTICS OF CORE PLACEMENTS



1 = Best 5 = Worst	Edge	Detached	Central	Two	Corners	Scattered
Flexibility of typical rental areas	2	1	3	4	2	5
Perimeter for rental areas	4	3	1	1	5	2
Ground floor high-rent area	3	1	3	4	2	5
Typical distance of travel from core	4	5	2	1	3	3
Clarity of circulation	3	4	2	1	3	5
Daylight and view for core spaces	2	1	5	5	1	4
Service connections at roof	3	4	2	1	5	3
Service connections at ground	3	4	2	1	5	3
Suitability for lateral bracing	4	5	1	1	2	3

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PLANNING THE INTERNAL ARRANGEMENT OF THE CORES

The ratio of the total floor area of the core or cores of a building to the floor area served varies widely from one building to the next. The average total area of the cores in 40- to 70-story New York City office buildings, including the stairways, toilets, elevators, and elevator lobbies, is approximately 27% of the open area of each floor served by the core. This percentage runs as high as 38% in some older buildings but is around 20% to 24% in office towers of more recent design. At the other extreme, the total core area of a three-story suburban office building is likely to be about 7% of the floor area served, because there are few elevators, much less lobby space for elevators, and much smaller shafts for mechanical and electrical services.

These percentages also vary with the relative requirements for mechanical and electrical services; they are higher in a hospital or laboratory and are much lower in a hotel or apartment building. Core area is directly related to the type of heating and cooling system used: The percentages quoted in the preceding paragraph apply to buildings with all-air systems. Buildings with air-and-water and all-water systems require less shaft space.

A building with a fan room on each floor will need very little core area for ductwork, but the fan room is likely to occupy at least as much floor space as the vertical ductwork it eliminates.

The structural scheme of a building can also have a direct effect on the core area. Of the total core area of a tall office building, about 12% is usually occupied by columns, bracing, walls, and partitions. This percentage is lower for lower buildings and can be very low in buildings whose core areas contain no columns or lateral bracing.

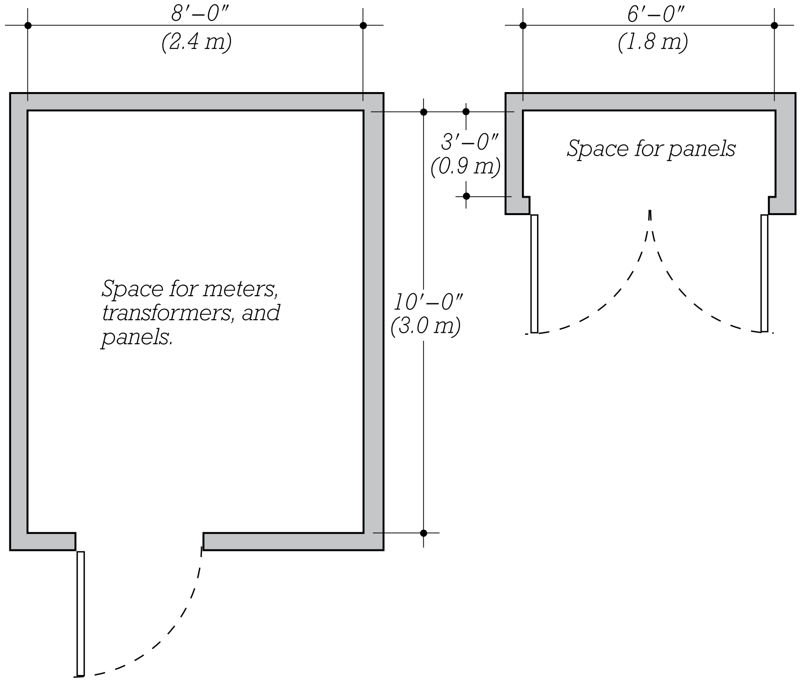
The most critical elements of the core, those that should be located first in at least a tentative way, are the columns and lateral bracing, the exit stairways, and the elevators and elevator lobbies. Next should come the plumbing walls and the shafts for ductwork. For help in laying out the structural elements, see pages 41–53. Details of the location and configuration of exit stairways are given on pages 271–272. Pages 207–209 give advice on the number, size, and layout of elevator shafts and lobbies. Plumbing walls are illustrated on page 201, and ductwork shafts can be sized using the chart on pages 218–219.

The chimney is another element for which there may be little flexibility of location. Usually the chimney exits from a corner of the boiler room. It may be sloped at an angle not less than 60° to the horizontal to bring it to a more convenient position in the core. For help in sizing chimneys, refer to page 186.

TOTAL SHAFT AREA

The total open area of all the mechanical and electrical shafts in a tall office building is normally equal to about 4% of the area served on each floor and can be estimated at about half this amount for a low-rise building. This area should be divided into at least two separate shafts to relieve the congestion that would otherwise occur where the vertical and horizontal distribution networks connect. It is especially effective to provide separate shafts for supply and return ducts because it is often possible to use a separate return shaft as a plenum, a shaft that is itself the duct. For maximum utility, the horizontal ratios of each shaft should lie in the range of 1:2 to 1:4. To allow sufficient space for connections to horizontal distribution networks at each floor, no shaft should adjoin stair towers or elevator shafts on more than one long side and one short side.

ELECTRICAL AND TELECOMMUNICATIONS DISTRIBUTION ROOMS



ELECTRICAL ROOM

SMALL ELECTRICAL OR TELECOMMUNICATIONS CLOSET

Rooms for the distribution of electrical power and telecommunications, often referred to as *closets* regardless of their size, are provided on every floor of a building. They must be accessible from public areas of the floor, stacked above one another, and kept free of plumbing, steam, and other types of wet piping. Typical sizes and configurations for electrical rooms are illustrated in the accompanying diagrams. In an office building, major rooms should be provided for each 15,000 to 20,000 sq ft (1400–1900 m^2) of floor area and so that no point on a floor lies more than 100–125 ft (30–40 m) from the closest one. If this is difficult to arrange, satellite rooms served by cables from the major ones may be used to supply electricity to the more distant areas. Electrical rooms do not normally require fire-resistance-rated enclosures unless they contain large transformers.

The electrical risers that connect stacked rooms may either pass through floor penetrations that are sealed to protect against the passage of fire and smoke or, in taller buildings, they may travel within dedicated vertical shafts abutting one wall of the rooms. In very tall buildings, such shafts may become so large as to be configured as complete rooms themselves, with their own entrances.

Telecommunications rooms should be provided for every floor and so that no point on the floor is more than 300 ft (90 m) from the closest one. For commercial office space, such rooms may measure 10 × 12 ft (3.0 × 3.7 m) internally. For less data-intensive occupancies, rooms as small as 4 × 5 ft (1.2 × 1.5 m) or even true closets as little as 3 ft deep by 4 ft wide (0.9 × 1.2 m) may be sufficient.

Most electrical and telecommunications rooms require dedicated cooling, with independent temperature control. Doors to these rooms open outward to avoid interfering with access to the equipment within.

FAN ROOMS

When local fan rooms' fresh air and exhaust air connections are provided by means of duct risers, these rooms should be placed against the shafts containing those ducts. If local fan rooms exchange air directly with the outdoors on each floor, they should be placed against outside walls, or if this is not possible, they can be connected to fresh air and exhaust louvers by horizontal ducts. Heated and chilled water must also be provided to the fan rooms, either via horizontal piping running from the building core or via vertical piping in an immediately adjacent shaft. Fan rooms should be stacked one above the other from floor to floor. See pages 190–192 and 218–219 for information on planning fan rooms.

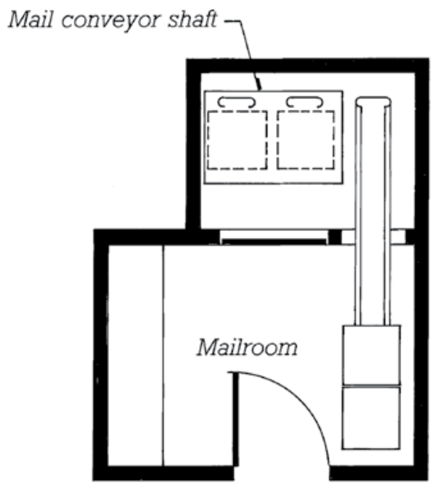
MAIL FACILITIES

Vertical gravity chutes for mail deposit are often provided in multistory buildings. The chute occupies an area of about 5 × 15 in. (125 × 375 mm) in plan and terminates in a receiving box in the base of the building.

Vertical mail conveyors are sometimes provided for delivery of mail in a large multistory office building. The mailroom at the base of the conveyor should be adjacent to the loading dock and can be sized at about 2⁄10 of 1% of the area it serves. The walls around the conveyor shaft itself will vary in plan from 4 ft × 4 ft 6 in. (1220 × 1370 mm) to 7 ft 3 in. × 8 ft 6 in. (2210 × 2590 mm) inside dimensions, depending on the system's capacity and manufacturer. The conveyor should discharge into a service mailroom of at least 6 × 7 ft (1830 × 2135 mm) on each floor. A 1- or 2-hour fire enclosure is required around the conveyor shaft.

PIPE RISERS FOR HEATING AND COOLING

The insulated pipes that conduct heated and chilled water to and from the spaces in a building require considerable space. In a tall apartment building or hotel, a clear shaft of 12 × 48 in. (300 × 1200 mm) is generally sufficient to serve two stacks of units. This may be sandwiched between units at the perimeter of the building or located adjacent to the central corridor, depending on where the heating and cooling equipment is located in the units.

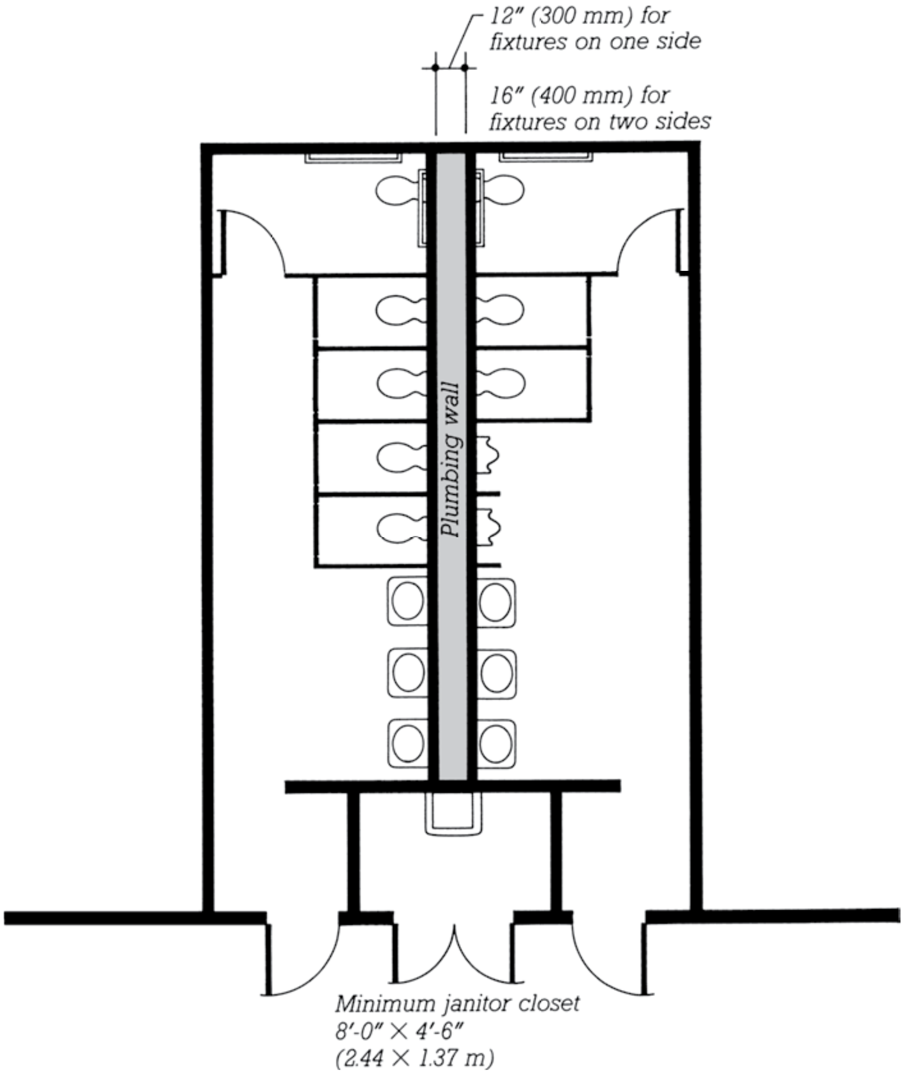


MAILROOM

PLUMBING WALLS, JANITOR CLOSETS, TOILET ROOMS, AND BATHING ROOMS

Fixtures in bathrooms, toilet rooms, shower rooms, kitchens, laundries, and other areas with plumbing should back up to plumbing walls. A plumbing wall has an internal cavity large enough to house the supply, waste, and vent piping necessary to serve the fixtures. Plumbing walls should be stacked vertically from the bottom of the building to the top. It is possible to offset plumbing walls a few feet from one floor to the next, but horizontal offsets are expensive and cause maintenance headaches. A typical plumbing wall arrangement, complete with janitor closet, is illustrated and dimensioned on the diagram to the right. The indicated internal widths of the plumbing wall are adequate for floor-mounted fixtures. If wall-hung fixtures are used, a 24-in. (600-mm) dimension is needed to accommodate the fixture carriers within the wall.

Fixture requirements for toilet rooms are established by plumbing codes. Requirements for the model codes included in this book are reproduced on the following pages. Where building use may change over time, consider providing adequate fixture counts for future uses, as it is costly and time-consuming to add plumbing facilities to existing facilities.



TOILET ROOM AND JANITOR'S CLOSET

Minimum Plumbing Fixture Requirements in the International Building Code

Consult the table on the facing page to determine the minimum number of plumbing fixtures required by the International Building Code, based on the Occupancy classification and number of occupants served. See pages 6–12 for more information on determining Occupancy classifications and page 303 for determining the occupant load. For occupancy types not listed in the table, select the most comparable classification in terms of patterns of use and occupant density.

When determining fixture requirements, the following should also be considered:

■ Fixture requirements are normally based on the assumption of equal numbers of male and female occupants.

■ Required toilet room facilities must be free of charge.

■ For male toilet facilities, urinals may be substituted for not more than two-thirds of the required water closets in assembly and educational occupancies, and not more than one-half of the required water closets in other occupancies.

■ Drinking fountains are not required in spaces with an occupant load of 15 or less.

■ Toilet facilities for public and employee use must be located within one story above or below and within a 500-ft (152-m) travel distance of the space served. Facilities may in most cases be shared between employees and the public.

■ In covered malls, toilet facilities may be located within individual stores, or centrally located not more than one story above or below and within a 300-ft (91-m) travel distance of the space served. For the public, travel distance is measured from the main entrance to any store or tenant space. For employees, it is measured from the employee's work area.

■ Toilet rooms may not open directly into rooms used for the preparation of food for public consumption.

■ In Institutional I-2 and I-3 Occupancies, employee and visitor toilet facilities must be separate from resident facilities.

■ In Residential R-2 Occupancies, each dwelling unit must be provided with a kitchen sink. At least one automatic clothes washer connection is required for every 20 dwelling units.

■ At least one service sink for maintenance personnel should be provided per floor or use area.

Toilet facilities shared by both sexes are permitted:

■ With single-use toilet and bathing rooms

■ For dwelling units and sleeping units

■ For buildings or tenant spaces with 15 or fewer occupants, Mercantile Occupancies with 100 or fewer occupants, or Business Occupancies with 25 or fewer occupants

■ Where facilities are designed for use by both sexes, water closets are within individual compartments, and urinals are visually separate from the remainder of the facility or are within individual compartments

Accessible Plumbing Facilities in the International Building Code

With few exceptions, all toilet and bath facilities within accessible buildings must be made accessible. In all cases, accessible buildings must provide at least one set of accessible facilities. Fully accessible toilet facilities are not required for single-occupant private offices, nonaccessible dwelling or sleeping units, facilities on nonaccessible floors, or facilities for intensive or critical care sleeping rooms.

Accessible toilet facilities must be located on accessible routes and equipped with at least one accessible fixture of each type. In toilet rooms with partitioned water closet compartments, at least 5% must be *wheelchair accessible*, and where six or more compartments are provided, an additional 5% must be *ambulatory accessible*, that is, be at least 36 in. (914 mm) in width, have an outward-swinging door, and be equipped with grab bars. Where sinks are provided, at least 5% (and at least one) must be accessible. Where only one urinal is provided, it need not be accessible.

Where drinking fountains are provided, at least half must be accessible. At a minimum, at least two accessible fountains are required, one for wheelchair-bound users and one for standing users. Alternatively, a single fountain complying with the dimensional requirements for both user types may be provided.

In A Assembly and M Mercantile Occupancies where a total of six or more water closets are required, at least one accessible, unisex family, or assisted-use toilet room must be provided for individuals and their assistants. In recreational facilities with separate-sex bathing rooms, at least one must be accessible. These facilities should have only one set of each fixture type. They must be located on accessible routes, not more than one story above or below other separate-sex toilet or bathing rooms, with a maximum travel distance along the accessible route of 500 ft (152 m) from those rooms. The fixtures provided in accessible unisex toilet and bathing rooms may be counted toward the overall fixture requirements of the space. In some Institutional occupancies, some portion of the required accessible toilet and bathing fixtures must be designed for assisted toileting and bathing.

VERTICAL DISTRIBUTION OF SERVICES FOR LARGE BUILDINGS

Occupancy	Water Closets	Lavatories	Drinking Fountains	Bathtubs/ Showers
A: Assembly				
A-1: Theaters, motion picture and performing arts facilities	Male: 1 per 125 Female: 1 per 65	1 per 200	1 per 500	None
A-2: Nightclubs, bars, taverns, dance halls	1 per 40	1 per 75	1 per 500	None
A-2: Restaurants, banquet halls, food courts	1 per 75	1 per 200	1 per 500	None
A-3: Auditoriums without fixed seating, galleries, exhibition halls, museums, lecture halls, libraries, arcades, gymnasiums	Male: 1 per 125 Female: 1 per 65	1 per 200	1 per 500	None
A-3: Places of worship	Male: 1 per 150 Female: 1 per 75	1 per 200	1 per 1000	None
A-3: Passenger terminals and transportation facilities	1 per 500	1 per 750	1 per 1000	None
A-4 and A-5: Indoor and outdoor arenas with up to 1500 seats	Male, first 1500 seats: 1 per 75 Female, first 1520 seats: 1 per 40 Additional seating: Male: 1 per 120 Female: 1 per 60	Male: 1 per 200 Female: 1 per 150	1 per 1000	None
B: Business	First 50 occupants: 1 per 25 Additional occupants: 1 per 50	First 80 occupants: 1 per 40 Additional occupants: 1 per 80	1 per 100	None
E: Educational	1 per 50	1 per 50	1 per 100	None
F: Factory	1 per 100	1 per 100	1 per 400	Emergency showers and eyewash stations may be required
I: Institutional				
I-1: Residential care	1 per 10	1 per 10	1 per 100	1 per 8
I-2: Hospitals, ambulatory nursing homes (residents only)	1 per room, or Two patient rooms may share one toilet room with direct access from each room		1 per 100	1 per 15
I-2: Visitors	1 per 75	1 per 100	1 per 500	
I-3: Prisons (residents only)	1 per cell	1 per cell	1 per 100	1 per 15
I-3: Reformatories, detention centers, correctional centers (residents only)	1 per 15	1 per 15	1 per 100	1 per 15
I-2 and I-3: Employee toilet facilities	1 per 25	1 per 35	1 per 100	None
I-4: Adult and child day care	1 per 15	1 per 15	1 per 100	1
M: Mercantile	1 per 500	1 per 750	1 per 1000	None
R: Residential				
R-1: Hotels and motels	1 per sleeping unit	1 per sleeping unit	None	1 per sleeping unit
R-2: Dormitories, fraternity houses, sorority houses, boardinghouses	1 per 10	1 per 10	1 per 100	1 per 8
R-2: Apartments	1 per dwelling unit	1 per dwelling unit	None	1 per dwelling unit
R-3: Congregate living facilities with16 or fewer persons	1 per 10	1 per 10	1 per 100	1 per 8
R-3: One- and two-family dwellings and lodging houses with five or fewer guestrooms	1 per dwelling unit	1 per 10	None	1 per dwelling unit
R-4: Residential care, assisted living facilities	1 per 10	1 per 10	1 per 100	1 per 8
S: Storage (not including parking)	1 per 100	1 per 100	1 per 1000	Emergency showers and eyewash stations may be required

This table was compiled from information contained in the International Building Code 2021. It does not represent an official interpretation by the organization that issues this code.

Minimum Plumbing Fixture Requirements in the National Building Code of Canada

Consult the table on the facing page to determine the minimum number of plumbing fixtures required by the National Building Code of Canada, based on the Occupancy classification and number of occupants served. See pages 13–17 for more information on determining Occupancy classifications and page 303 for determining the occupant load.

In determining fixture requirements, the following should also be considered:

- Fixture requirements should be based on the assumption of equal numbers of male and female occupants, unless an unequal distribution of the sexes in the occupant population can be demonstrated with reasonable accuracy.
- Under most circumstances, separate toilet facilities are required for each sex. Separate facilities are not required for the following Occupancies with an occupant load of 10 or less: Assembly, B-3 Care, Residential, Business and Personal Services, Mercantile, and Industrial.
- For male toilet facilities, urinals may be substituted for up to two-thirds of the required water closets.
- For Business and Personal Service Occupancies with a floor area of more than 600 m^2 (6460 sq ft), toilet facilities must be available to the public.

Accessible Toilet Facilities in the National Building Code of Canada

Most buildings must provide at least one accessible, barrier-free washroom. All washrooms on floors requiring barrier-free access must themselves be barrier-free, except that barrier-free washrooms are not required:

- Within a B-3 Care or C Residential Occupancy suite
- Where other barrier-free facilities are located on the same floor area and within a path of travel of 45 m (148 ft)
- Within D Business and Personal Services, E Mercantile, and F Industrial Occupancies, individual suites less than 500 m^2 (5380 sq ft) in area, and that are completely separated from the rest of the building

Where showers are provided, at least one barrier-free stall must be provided, except in B-3 Care and C Residential Occupancy suites. Where drinking fountains are provided, at least one barrier-free fountain must be provided.

Special barrier-free, single-fixture, unisex *universal toilet rooms* may be provided as an alternative to providing barrier-free facilities within single-sex facilities. When universal toilet rooms are provided, the occupant load used to calculate fixture requirements for the general public may be reduced by 10 persons in Assembly, Business and Personal Services, Mercantile, or Industrial Occupancies, as well as in primary schools, day care facilities, places of worship, and undertaking premises. If only one universal toilet room is provided, the water closet in that room generally may not be counted toward the water closet requirements of the building.

VERTICAL DISTRIBUTION OF SERVICES FOR LARGE BUILDINGS

Occupancy	Number of Occupants of Each Sex	Number of Water Closets for Each Sex	Number of Lavatories
A: Assembly			
Assembly spaces, except those listed below	1–25	Male: 1; Female: 1	At least 1, and not less than 1 per every 2 water closets
	26–50	Male: 1; Female: 2	
	51–75	Male: 2; Female: 3	
	76–100	Male: 2; Female: 4	
	101–125	Male: 3; Female: 5	
	126–150	Male: 3; Female: 6	
	151–175	Male: 4; Female: 7	
	176–200	Male: 4; Female: 8	
	201–250	Male: 5; Female: 9	
	251–300	Male: 5; Female: 10	
	301–350	Male: 6; Female: 11	
	351–400	Male: 6; Female: 12	
	Over 400	Male: 7 plus 1 for each additional increment of 200 occupants over 400 Female: 13 plus 1 for each additional increment of 100 occupants over 400	
Primary schools and day care centers	Any number	Male: 1 per 30; Female: 1 per 25	Same as above
Places of worship, undertaking premises	Any number	1 per 150	
B: Care and Detention			
B-1, B-2: Detention, medical treatment facilities	Any number	Based on the specific needs of the occupants, determined on a case-by-case basis	Same as above
B-3: Care facilities	Any number	1 per 10	Same as above
C: Residential			
Except dwelling units	Any number	1 per 10	Same as above
Dwelling units	Any number	1 per unit	Same as above
D: Business and Personal Services	1–25	1 for each sex	Same as above
	25–50	2 for each sex	
	Over 50	3 for each sex plus 1 for each additional increment of 50 occupants over 50	Same as above
E: Mercantile	Any number	Male: 1 per 300 Female: 1 per 150	Same as above
F: Industrial	1–10	1	Same as above
	11–25	2	
	26–50	3	
	51–75	4	
	76–100	5	
	Over 100	6 plus 1 for each additional increment of 30 occupants over 100	

This table was compiled from information contained in the National Building Code of Canada 2015. It does not represent an official interpretation by the organization that issues this code.

STANDPIPES

A *standpipe* is a steel water pipe extending vertically through a building, with fire hose connections at every floor. A *wet standpipe* is continuously filled with water. A *dry standpipe* normally contains no water. In the case of a building fire, water may be supplied to it automatically, by a fire control system, or manually, by fire department pumper trucks connecting at the front of the building at street level. A *combination standpipe*, normally wet, supplies water to the building's sprinkler system as well as to required fire hose connections. In addition to providing connections for hoses carried into the building by firefighters, standpipes may be prefitted with permanent lighter-duty hoses intended for early fire suppression efforts before larger hoses arrive. Depending on the standpipe type, the minimum nominal diameter is 4 to 6 in. (100 to 150 mm).

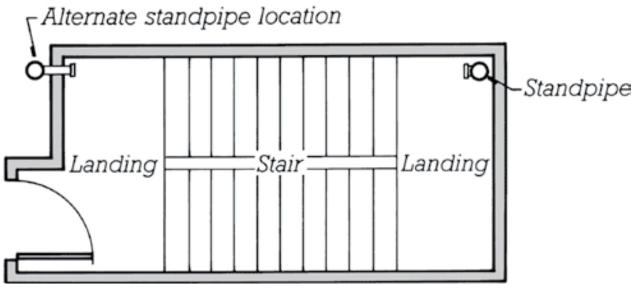
Building code standpipe requirements vary with building height, area, occupancy, and the extent of sprinklers. The International Building Code generally requires standpipes in buildings with floors more than 30 ft (9.1 m) above or below the level of firefighter access and includes special requirements for assembly spaces, covered malls, underground buildings, parking garages, and other unique occupancy conditions. The National Building Code of Canada requires standpipes in buildings with more than three stories, with top-story ceilings more than 14 m (46 ft) above grade, and in shorter buildings in which certain occupancies exceed 1000 m^2 (10,800 sq ft) or more in area per floor.

Where standpipes are required, they must be provided in every exit enclosure. Where remote portions of a story are located more than 150 to 200 ft (45 to 60 m) from the nearest standpipe connection in an exit, additional standpipes may be required to improve coverage. Hose connections to the standpipe may be located on stair landings between floors, such that each connection can serve two levels.

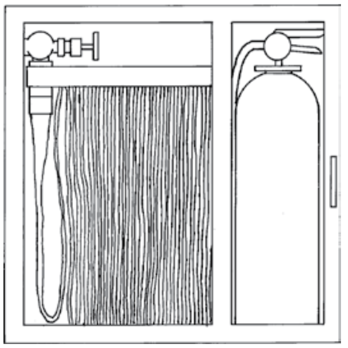
Where floor levels are not sprinklered, additional *hose stations*, cabinets with prefitted hoses, may also be required, dispersed so as to provide full coverage of the floor area. Portable fire extinguishers are often incorporated into these cabinets. A typical recessed wall cabinet for a wet standpipe hose and a fire extinguisher is 2 ft 9 in. (840 mm) wide, 9 in. (230 mm) deep, and 2 ft 9 in. (840 mm) high.

Building fire sprinklers may be served by wet standpipes dedicated solely to the sprinkler system or combination standpipes. From the standpipe, horizontal piping branches at each floor and, if it is concealed, runs just above the finish ceiling. An assembly of valves and alarm fittings is furnished at the point where the sprinkler system joins the domestic water system, usually in the same room with the domestic water pumps.

In the case of a significant building fire, the building's water supply may become overwhelmed and unable to provide sufficient water to both sprinklers and standpipes for fire hoses. To prevent this, the water supply to these systems is augmented by firefighter pumper trucks drawing water from nearby fire hydrants and delivering it to standpipe connections, either Y-shaped *Siamese connections* on the outside of the building or smaller interior *floor outlets*.



STANDPIPES WITHIN AN EXIT STAIR ENCLOSURE



HOSE CABINET

SIAMESE CONNECTION

DESIGNING ELEVATORS AND ELEVATOR LOBBIES

For buildings up to 24 stories, use the tables to the right to arrive at preliminary numbers and sizes of elevator cars. In taller buildings, the number of cars may be reduced by as much as one-third with the use of higher-speed elevators, grouping of elevators into express and local service banks, and advanced control systems that more efficiently allocate passengers to cars. Where the table indicates that only one elevator is required, consider providing a second to maintain service in at least one elevator when the other is being serviced.

Walking distance should not exceed 150 ft (45 m) from an elevator lobby to any apartment or hotel room, or 200 ft (60 m) to any business work area. In many buildings, elevators must also be sized to accommodate persons with disabilities or emergency aid personnel with medical stretchers. For more information, see page 287 for the International Building Code and page 291 for the National Building Code of Canada.

APPROXIMATE NUMBERS OF ELEVATOR SHAFTS

Use	Number of Shafts
Apartment and other Multifamily Buildings	1 for 90–100 living units and every 6 floors above the entry level, plus 1 service elevator for buildings with more than 4 to 9 floors
Hotels	1 for 75 to 80 rooms and every 4 floors above the entry level, plus 1 service elevator for every 2 passenger elevators
Office Buildings	1 for every 50,000 ft² (4600 m²) of area served and every 2 to 2½ floors above the entry level, plus 1 service elevator per 250,000 ft² (23,000 m²) of area served
Healthcare Buildings	2 for every 100 patient beds or every 50 patient care rooms. Consider additional separate elevators for staff, operating areas, kitchens, and other services.

ELEVATOR DIMENSIONS

Use	Capacity	Inside Car Dimensions	Inside Shaft Dimensions (width × depth)
Apartments, Hotels, Office Buildings, Stores	2000 lb (900 kg) or 2500 lb (1140 kg)	5′-8″ × 4′-3″ (1727 × 1295 mm) 6′-8″ × 4′-3″ (2032 × 1295 mm)	6′-7″ × 7′-4″ (2006 × 2235 mm) 8′-4″ × 6′-8″ (2540 × 2032 mm)
Office Buildings, Hotels, Stores	3000 lb (1360 kg)	6′-8″ × 4′-9″ (2032 × 1448 mm)	8′-4″ × 7′-5″ (2540 × 2261 mm)
Office Buildings, Stores	3500 lb (1590 kg)	6′-8″ × 5′-5″ (2032 × 1651 mm)	8′-4″ × 8′-1″ (2540 × 2464 mm)
Hospitals, Nursing Homes	6000 lb (2730 kg)	5′-9″ × 10′-0″ (1750 × 3050 mm)	8′-2″ × 11′-9″ (2490 × 3580 mm)
Freight, Service	4000 to 6000 lb (1820 to 2730 kg)	8′-4″ × 10′-0″ (2540 × 3050 mm)	10′-10″ × 10′-8″ (3300 × 3250 mm)

Laying Out Banks of Elevators

For efficient service, the largest building zone that should be served by a single bank of elevators is 10 to 16 floors (not including the entry level) and between 1500 and 2500 occupants. Elevators serving the same zone should be arranged so that waiting persons can keep all the doors in sight at one time. A bank of three or four elevators in a single row, or up to eight elevators in two facing rows of four each, is the largest desirable. Banks serving different zones may open on opposite walls of the same elevator lobby or onto separate lobbies. The minimum width of an elevator lobby serving a single row of elevators is 8 ft (2.45 m), or for a lobby with elevators on both sides, 10 ft (3 m).

Building codes in some circumstances require elevator lobbies to be separated from surrounding floor areas to reduce the risk of smoke or fire spreading easily through the elevator shaft to adjacent floors. In the International Building Code, elevator entrances serving more than three stories must be protected by lobbies, except when elevator shafts are pressurized, in non-high-rise (see page 297) fully-sprinklered buildings without occupancies I-2 or I-3, or on ground floors when that floor level is sprinklered. In the National Building Code of Canada, except where elevators are within permitted interconnected floor space (see page 379), they must be separated from adjacent floor areas.

Elevator shafts are noisy and should not be located next to acoustically sensitive spaces—for example, sleeping or dwelling units in residential buildings.

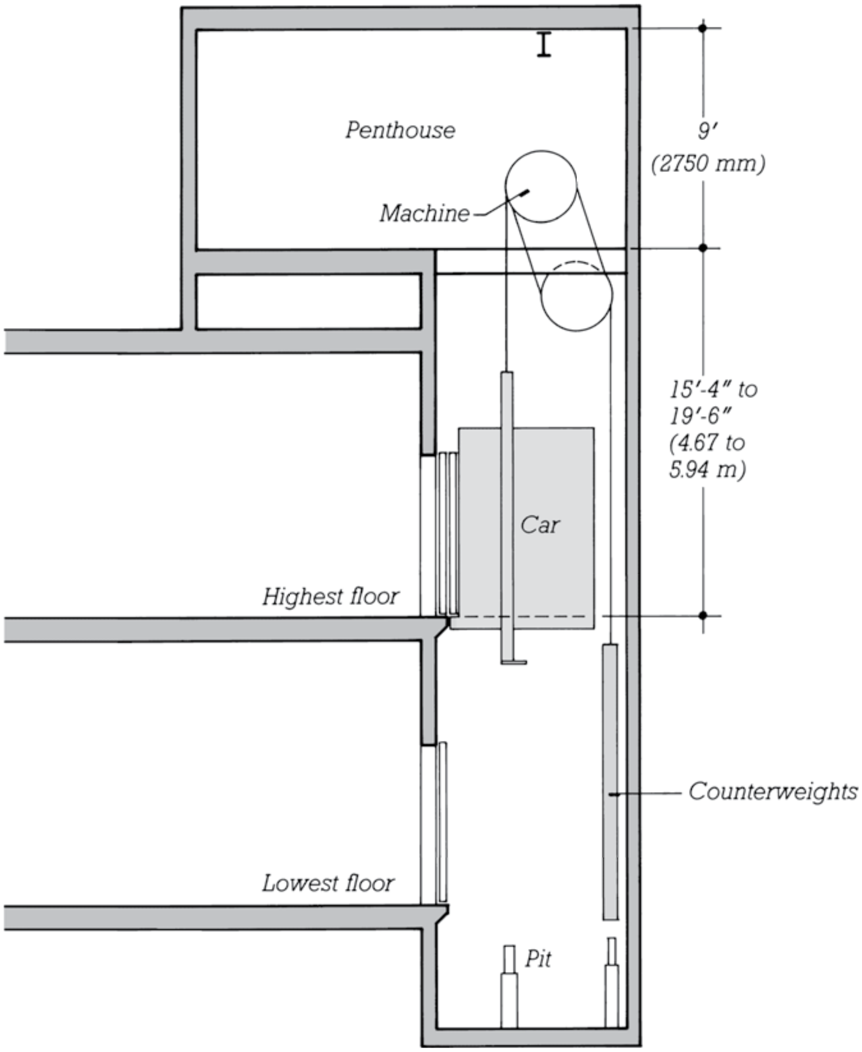
Elevator cars ordinarily have doors on one side only. Cars with doors on opposing sides necessitate a shaft that is slightly wider to allow for counterweight placement alongside the car.

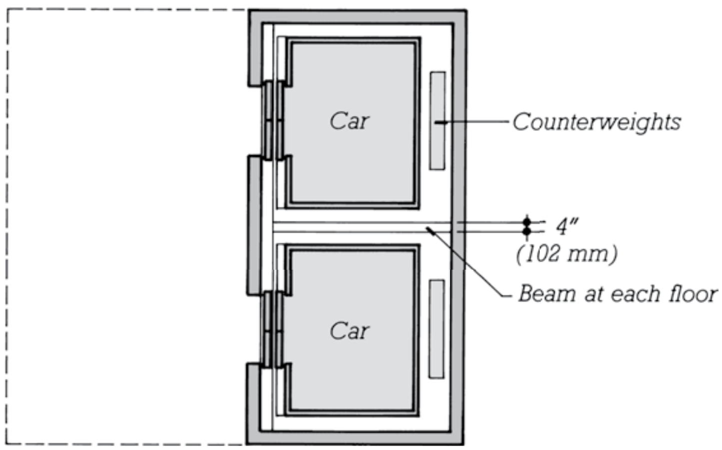
Service elevators should open to separate service areas. Mailrooms, receiving rooms, and maintenance and housekeeping facilities should relate closely to these elevators.

ELEVATOR TYPES, PENTHOUSES, PITS, AND MACHINE ROOMS

The choice of elevator type is based on the building height and number of floors served. For travel up to five floors and 40 to 60 ft (12 to 18 m), hydraulic elevators are usually the most economical. With this type, a hydraulic piston is located either in a drilled well at the bottom of the shaft or within the shaft itself. A machine room approximately 45 sq ft (4.2 m^2) in area is required, connected to the elevator shaft by hydraulic lines and electrical control wiring. Its preferred location is adjacent to the elevator shaft on the lowest level served by the elevator. However, the machine room is also noisy and should not be located close to acoustically sensitive areas. When necessary, it may be located on other levels or at a greater distance from the shaft. The inside top of the elevator shaft itself must extend 13–14 ft (3.9–4.25 m) above the uppermost finish floor level served; frequently this results in the shaft construction projecting at least several feet above adjacent roof areas. When referring to the Elevator Dimensions table on the previous page, inside shaft dimensions should be increased by 6 in. (150 mm) in width and reduced by 12 in. (300 mm) in depth from those listed to account for differences in the lifting machinery of this elevator type.

At greater heights, electric traction elevators are required. For serving vertical distances up to approximately 250 ft (75 m) or 25 floors, *machine room-less* elevators are the most efficient and least consuming of space. With this type, a relative compact and efficient hoisting motor is located within the elevator shaft itself. Capacities of up to 4000 to 5000 lb (1800 to 2300 kg) are available. For preliminary inside





shaft dimensions, use the sizes listed in the Elevator Dimensions table on page 207. Machine room-less elevators require separate control rooms or closets. A space as little as 2 ft deep and 4 ft wide (0.6 m × 1.2 m) directly adjacent to the elevator shaft may be sufficient for some systems. Or a room up to 25 to 65 sq ft (2.5 to 6 m^2) in area, depending on the number and capacity of elevators in operation, may be required. Most commonly, this closet or room is located adjacent to the elevator shaft, near its top. In other cases, it may be located as far as 100 ft (30 m) from the shaft. The minimum height required from the uppermost floor level served to the inside top of the shaft varies considerably among the available configurations. Machine room-less elevators are quieter than alternative types and consume significantly less electrical power.

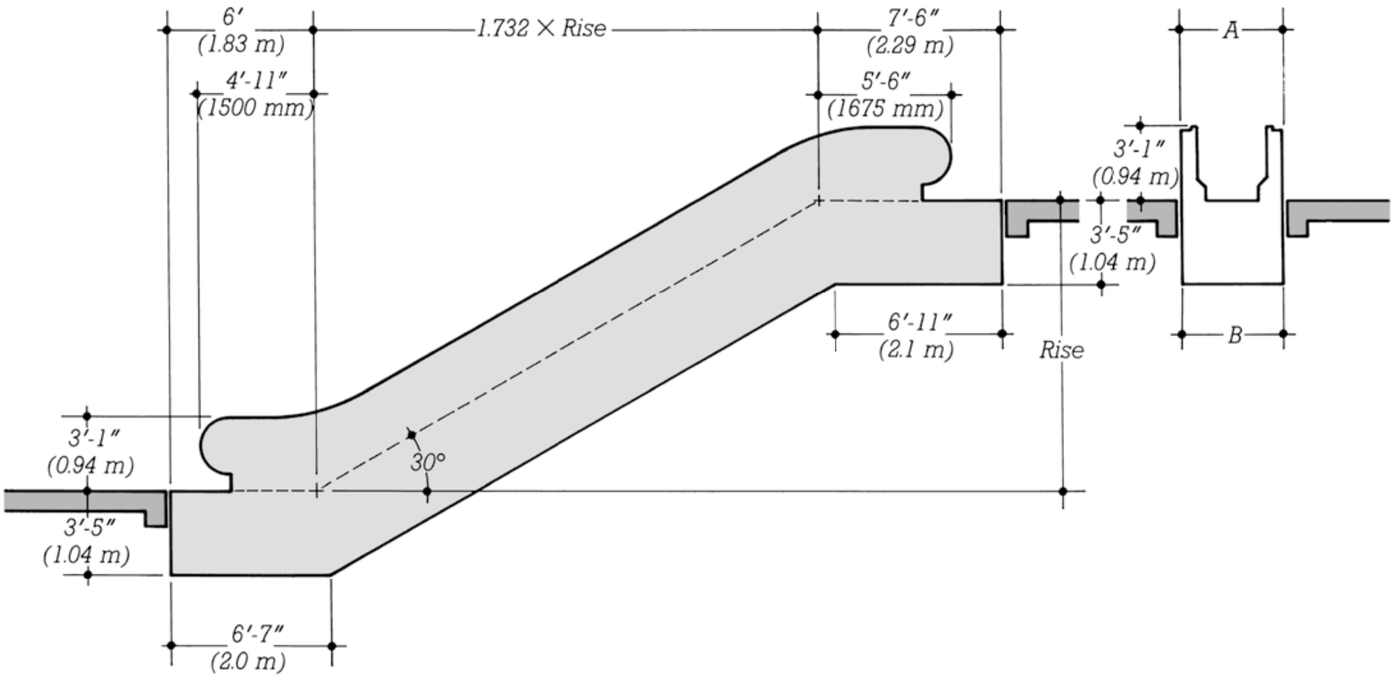
For vertical distances exceeding the capabilities of machine room-less elevators, conventional electric traction elevators with the hoisting machinery located in a penthouse room above the top of the elevator shaft are used. This room's inside dimensions must be approximately 9 ft (2.7 m) high, as wide as the shaft itself, and 16–18 ft (5–5.5 m) long. It is located exactly over the top of the elevator shaft, extending beyond the shaft on the side above the elevator doors (see figure at right). Below the elevator machine room, the inside top of the elevator shaft itself must extend from 15 to 20 ft (4.5 to 6.1 m) above the uppermost finish floor level served. For this reason, the penthouse must frequently be raised above the adjacent roof surface, making it a significant presence on the building rooftop.

Every elevator shaft must terminate with a pit at the bottom. For electric traction elevators, the inside depth of the pit below the lowest floor level served varies from approximately 5 to 13 ft (1.5 to 4 m), depending on the speed and capacity of the elevator—the bigger and faster the elevator, the deeper the pit. Hydraulic elevators normally require a pit 4 ft (1.2 m) deep.

ESCALATORS

Escalators are useful in situations where large numbers of people wish to circulate among a small number of floors on a more or less continual basis. An escalator cannot be counted as a means of egress. The structural and mechanical necessities of an escalator are contained in the integral box that lies beneath the moving stairway. Structural support is required only at the two ends of the unit. Some basic dimensional information on escalators is tabulated below.

	32″ Escalator	48″ Escalator
A	3′-9″ (1145 mm)	5′-1″ (1550 mm)
B	3′-7″ (1090 mm)	4′-11″ (1500 mm)



A CHECKLIST OF CORE COMPONENTS

The following is an alphabetical listing of components that are often incorporated into the cores of a building. For more information on any component, follow the accompanying page reference.

Chimneys (page 186)
Drinking fountains and water coolers (pages 202–204)
Electrical closets (page 199)
Elevators (pages 207–209)
- Dumbwaiters and vertical conveyors
- Elevator lobbies
- Freight elevators and freight rooms
- Passenger elevators
- Service elevators and service lobbies

Escalators (page 209)
Fan rooms (page 200)
Fire hose and fire extinguisher cabinets (page 206)
Janitor closets (page 201)
Kitchens
Mail facilities (page 200)
- Mail chutes
- Mail conveyors
- Mailrooms

Plumbing walls (including waste and vent pipes) (page 201)

Refuse facilities (page 195)
- Refuse chute
- Refuse room

Shafts (pages 196–198)
- Domestic water piping:
  - Chilled drinking water supply and return piping
  - Domestic cold water supply and return piping
  - Domestic hot water supply and return piping
  - Liquid soap supply piping to toilet rooms
  - Supply riser to rooftop gravity tank
- Electrical and communications shafts:
  - Electrical wires or bus bars
  - Life safety communications wiring: Alarms, smoke and heat detectors, firefighter communications
  - Telephone, telex, local area networks, cable television, community antenna, etc.
- Heating and cooling shafts:
  - Control wiring
  - Ducts (page 218)
    - Exhaust ducts from toilets, baths, janitor closets, shower rooms, locker rooms, storage rooms, kitchens, corridors, fume hoods, laboratory areas, workshop areas, industrial processes (page 190)
    - Fire exhaust and pressurization ducts
    - Outdoor air and exhaust air ducts to local fan rooms
    - Supply ducts (page 218)
    - Return ducts (page 218)
  - Piping (heating and cooling shafts)
    - Air piping for controls
    - Chilled water supply and return
    - Condenser water supply and return between chilled water plant and cooling towers
    - Fuel oil piping
    - Gas piping
    - Hot water and/or steam supply and return
- Piping, miscellaneous: Compressed air, vacuum, deionized water, distilled water, fuel gas, medical gases, scientific gases, industrial gases
- Piping, plumbing waste and vent (pages 200–201)
- Piping, storm drainage risers from roofs and balconies

Sprinkler risers (page 206)
Stairways (pages 196–198)
Standpipes, fire (page 206)
Structure (pages 42, 50–53)
- Beams and girders, including special support around shafts and under heavy equipment
- Bracing
- Columns
- Shear walls

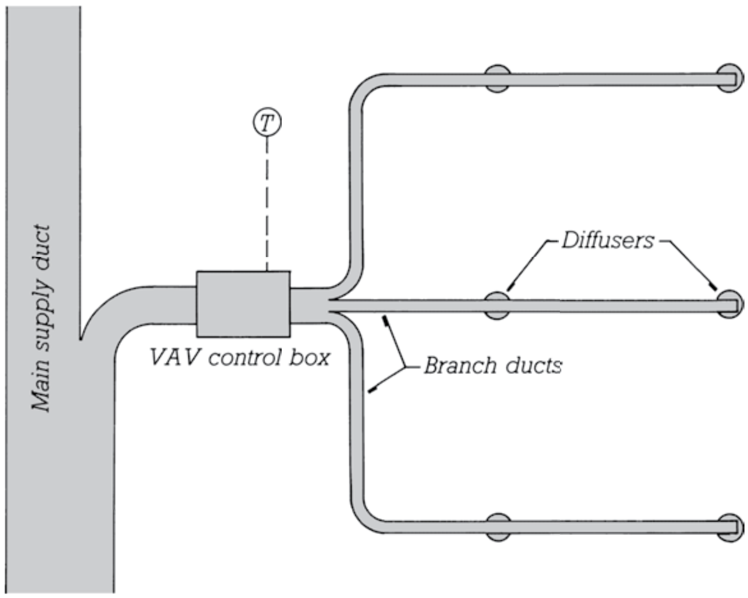
Telecommunications closets (page 199)
Toilet rooms (pages 201–205)

The horizontal distribution system for mechanical and electrical services in a large building should be planned simultaneously with the structural frame and the interior finish systems, because the three are strongly interrelated. The floor-to-floor height of a building is determined in part by the vertical dimension needed at each story for horizontal runs of ductwork and piping. The selection of finish ceiling, partition, and floor systems is often based in part on their ability to contain the necessary electrical and mechanical services and to adjust to future changes in these services. All these strategies involve close cooperation among the architect and the structural and mechanical engineers.

CONNECTING HORIZONTAL AND VERTICAL DISTRIBUTION LINES

Horizontal mechanical and electrical lines must be fed by vertical lines through smooth, functional connections. Plumbing waste lines, which must be sloped to drain by gravity, have top priority in the planning of horizontal service lines; if they are confined to vertical plumbing walls, they will not interfere with other services. Sprinkler heads, which have the second-highest priority in the layout of horizontal services, are served from the fire standpipe by horizontal piping that seldom exceeds 4 in. (100 mm) in outside diameter. The spacing of the heads is coordinated with the placement of walls and partitions; the maximum coverage per head is about 200 sq ft (18.6 m^2) in typical light-hazard buildings. Coverage in industrial and storage buildings containing flammable materials ranges from 90 to 130 sq ft (8.4 to 12.1 m^2) per head.

Air conditioning ducts, the next priority, branch out from a local fan room or from vertical ducts in supply and return shafts. Return ducts are often very short and confined to the interior areas of the building. Supply ducts extend from the main ducts through VAV or mixing boxes, then through low-velocity secondary ducts to air diffusers throughout the occupied area of the floor, with special emphasis on the perimeter, which may be on an independent, separately zoned set of ducts. Diffusers are generally required at the rate of four to seven diffusers per 1000 sq ft (100 m^2). For some typical diffuser designs, see the illustration on page 216.



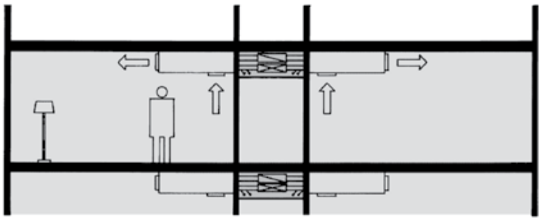
PLAN OF VAV DUCTING

GROUPED HORIZONTAL DISTRIBUTION

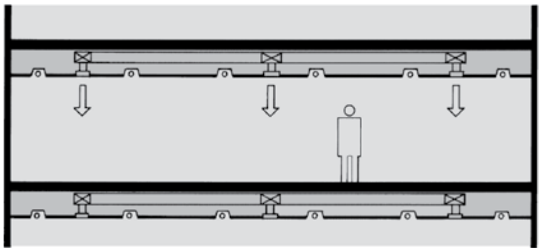
Sometimes the major runs of ductwork, piping, and wiring can be grouped in the ceiling area above the central corridor of each floor of a building, leaving the ceilings of the surrounding rooms essentially free of such service items. This works especially well in hotels, dormitories, and apartment buildings that rely on above-ceiling all-water or electric equipment in the area adjacent to the corridor for heating, cooling, and ventilating. A low corridor ceiling is readily accepted in exchange for high, unobstructed space in the occupied rooms, where the structure may be left exposed as the finish ceiling, saving cost and floor-to-floor height. If the building has a two-way flat plate or hollow core precast slab floor structure, the overall thickness of the ceiling–floor structure can be reduced to as little as 8 in. (200 mm). Conduits containing wiring for the lighting fixtures may be cast into the floor slabs or exposed on the surface of the ceilings. Wiring to wall outlets is easily accommodated in permanently located partitions.

FLOORWIDE HORIZONTAL DISTRIBUTION

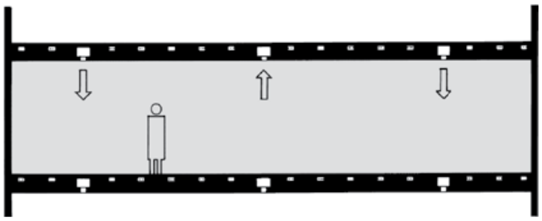
In broad expanses of floor space, particularly where all electrical and communications services must be available at any point in the area, an entire horizontal layer of space is reserved on each story for mechanical and electrical equipment. This layer may be beneath a raised access floor just above the structural floor. It may also lie within the structural floor or just beneath the floor, above a suspended ceiling. Sometimes combinations of these locations are used.



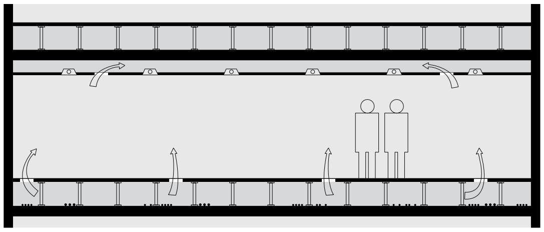
GROUPED HORIZONTAL DISTRIBUTION OVER A CENTRAL CORRIDOR



FLOORWIDE ABOVE-CEILING HORIZONTAL DISTRIBUTION



FLOORWIDE IN-FLOOR HORIZONTAL DISTRIBUTION



FLOORWIDE RAISED ACCESS FLOOR HORIZONTAL DISTRIBUTION

HORIZONTAL DISTRIBUTION OF SERVICES FOR LARGE BUILDINGS

Distribution above a Suspended Ceiling

Above a ceiling, wiring is run in conduits or cable trays attached to the structure above. Lighting fixtures are served directly from this horizontal wiring. Outlets on the floor below may be served by electrified partitions or power poles. Outlets on the floor above may be fed via poke-through fixtures that are cut through the structural floor. Poke-through fixtures can be added or removed at any time during the life of the building; their major disadvantage is that electrical work being done for the convenience of a tenant on one floor is done at the inconvenience of the tenant on the floor below.

Distribution within the Structural Floor

Electrical and communications wiring may be embedded in the floor slab in conventional conduits. For greater flexibility in buildings where patterns of use are likely to change over time, systems of cellular steel decking over steel framing, or cellular raceways cast into a topping over concrete slabs, may be selected. These provide a treelike structure: The trunk is a wiring trench that runs from the electrical closet to the outside wall of the building, and the branches are the hollow cells that run in the perpendicular direction. Electrical and communications wires and outlets can be added, removed, or changed at any time during the life of the building. Cellular steel decking can affect the layout of the beams and girders in a steel-framed building: For optimum distribution of wiring, the cells in the decking generally run parallel to the wall of the core, and for structural reasons the cells must run perpendicular to the beams. This requires close coordination among the architect and the electrical and structural engineers.

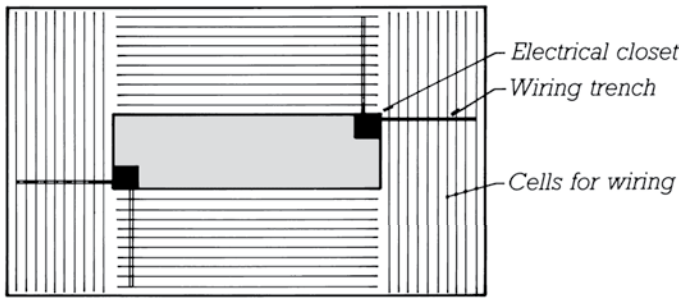
Distribution above the Structural Floor

A raised access floor system allows maximum flexibility in running services because it can accommodate piping and wiring with equal ease. It is especially useful in areas with large numbers of computers or anywhere else frequent changes in wiring for data and power are likely. It is also valuable in retrofitting old buildings for modern services.

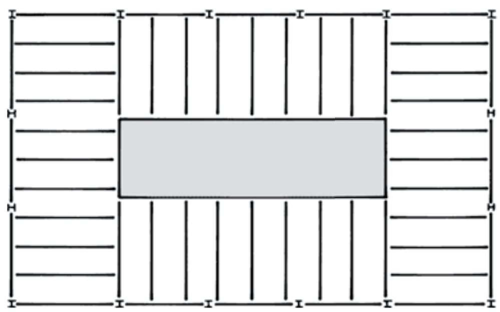
With *underfloor air distribution (UFAD)*, conditioned air from the air-handling system is distributed from beneath the raised floor as well. Most commonly, either the plenum space is pressurized and supply air naturally enters the occupied space through special air outlets in the floor, or fan-driven floor outlets are used with an unpressurized plenum. Less frequently, the supply air is ducted to floor registers, allowing closer individual control of the air delivered to each register but at the expense of added ductwork. Return air is drawn into the plenum above ceiling and then returned to the fan room or air handling unit. UFAD provides more efficient distribution of conditioned air within the occupied space and can increase occupant comfort in comparison to systems in which air is distributed from above the ceiling. The elimination of most horizontal ductwork can also frequently lead to reduced floor-to-floor heights in the building. UFAD is most often used with variable air volume systems (see page 174).

Access floor systems can be constructed to almost height desired above the structural deck. When underfloor air distribution is not included, heights from 4 to 8 in. (100 to 200 mm) are common. With UFAD, floors are typically raised from 12 to 24 in. (300 to 600 mm).

Undercarpet flat wiring may be used instead of a raised access floor in buildings with moderate needs for future wiring changes. Flat wiring does not increase the overall height of the building, as raised access floors usually do, but it does not offer the unlimited capacity and complete freedom of wire location of the raised floors. Flat wiring is used in both new buildings and retrofit work.

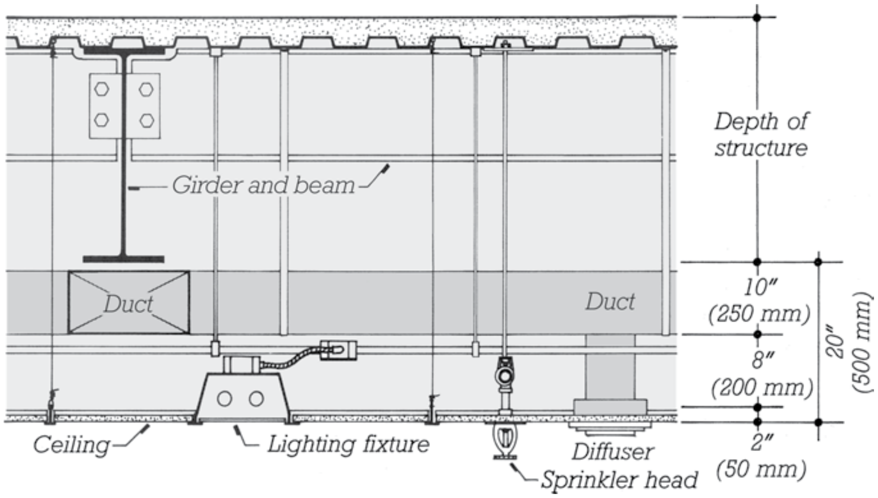


PLAN OF CELLULAR STEEL DECKING



STEEL FRAMING PLAN FOR CELLULAR STEEL DECKING

DESIGNING THE CEILING/FLOOR PLENUM SPACE



SECTION THROUGH A CEILING/FLOOR ASSEMBLY

Ductwork, which is often too large and bulky to fit above or within the structural floor, is most frequently located above the ceiling. There, it must share the above-ceiling plenum space with structural members and other systems. This requires careful planning. Generally, the lowest stratum, about 8 in. (200 mm) thick, is reserved for the sprinkler piping and lighting fixtures. Lighting fixture selection plays an important role in determining the thickness of this layer, because some types of lighting fixtures require more space than others. The ducts, which are usually 8 to 10 in. (200 to 250 mm) deep, run between this layer and the beams and girders. Adding about 2 in. (50 mm) for the thickness of a suspended ceiling, we see that a minimum height of about 18 in. (460 mm), and preferably 20 in. (500 mm), must be added to the thickness of the floor structure and fireproofing in a typical building to allow for mechanical and electrical services. A larger dimension is often called for, depending on the requirements of the combination of systems that is chosen.

As an example, let us assume that a steel-framed building has a maximum girder depth of 27 in. (690 mm) and a 4-in. (100-mm) floor slab, for a total floor structure height of 31 in. (790 mm). Adding 20 in. (510 mm) for ceiling and services, we arrive at an overall ceiling-to-floor height of 51 in. (1300 mm) that must be added to the desired room height to give the floor-to-floor height of the building. If fireproofing must be added to the girders, this dimension will increase by a couple of inches (50 mm or so).

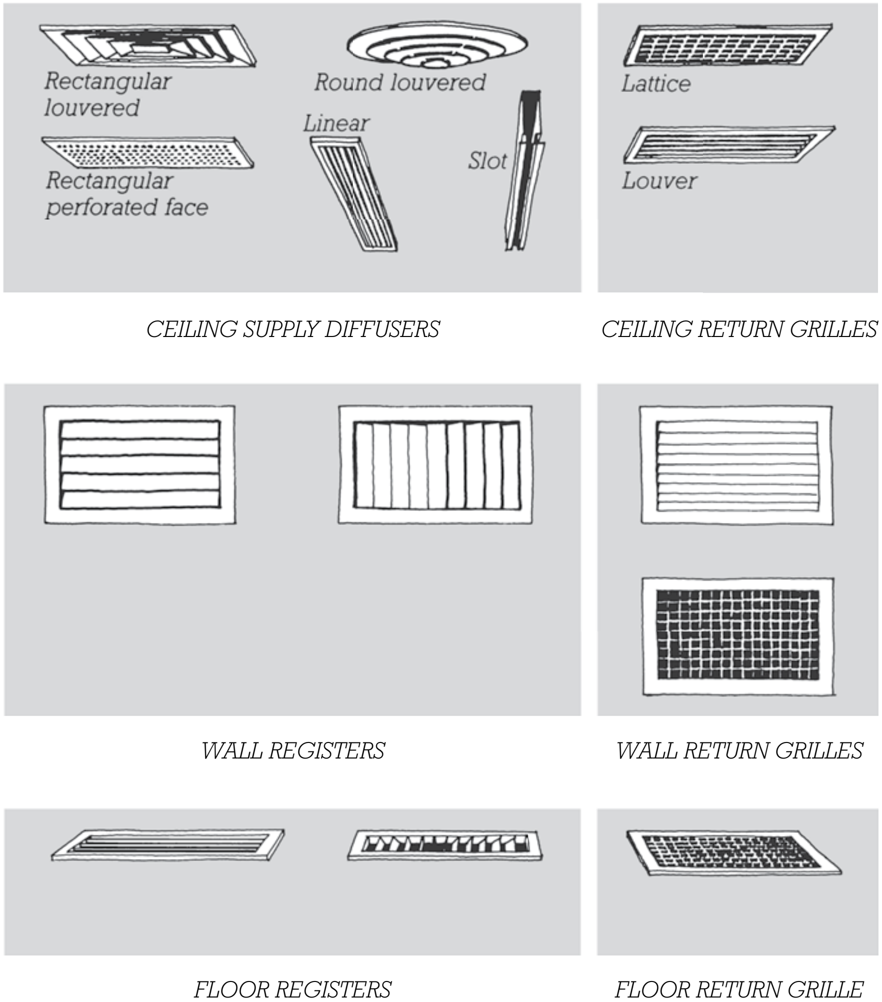
There is tremendous economic pressure to reduce this height to a practical minimum in a tall building. A few inches saved per floor adds up to significant savings in the cost of the structure, core components, and cladding. Sometimes it is possible to arrange the framing so that ductwork never passes beneath a girder. If the ductwork must cross the girders, the designers should explore such options as shallower ducts, running the ducts through holes cut in the webs of the girders, or reducing the depth of the girders by using a heavier steel shape. In the average tall office building, the height of the ceiling/floor assembly is about 46 in. (1170 mm).

In some medical, research, and industrial buildings, the underfloor services are unusually complex, bulky, and subject to change. In these cases, the layer above the ceiling and below the floor structure is expanded to a height that allows workers to walk freely in it, and the ceiling is strengthened into a structure that can support their weight. Such an *interstitial ceiling* allows workers to maintain and change the services without disrupting the occupied spaces above or below.

With all its service penetrations—lighting fixtures, air diffusers and grilles, sprinkler heads, smoke detectors, intercom speakers—a ceiling can take on a visually chaotic appearance. It is advisable to compose the relationships of these penetrations carefully on a reflected ceiling plan.

EXPOSED VERSUS CONCEALED SERVICES

In many buildings, the designer has a choice between exposing the mechanical and electrical services and concealing them above a suspended ceiling. Exposed services are the rule in warehouses and industrial buildings. In other types of buildings, exposed pipes and ducts can have an attractive sculptural complexity. They are easy to reach for maintenance and revision. They make sense in many large, open buildings (athletic arenas, exhibition halls), as well as in certain other kinds of buildings in which full-height partitions are not often changed and a frank, functional appearance is appropriate (schools, art galleries, pubs and restaurants, avant-garde stores). There are some disadvantages: Exposed services that must look good are more expensive to design and install. If they are painted, this cost must be added. They also need to be cleaned from time to time. Although exposed services are readily accessible for changes, such changes must be made with care. For these reasons, it is usually cheaper to install a suspended ceiling than to omit one.

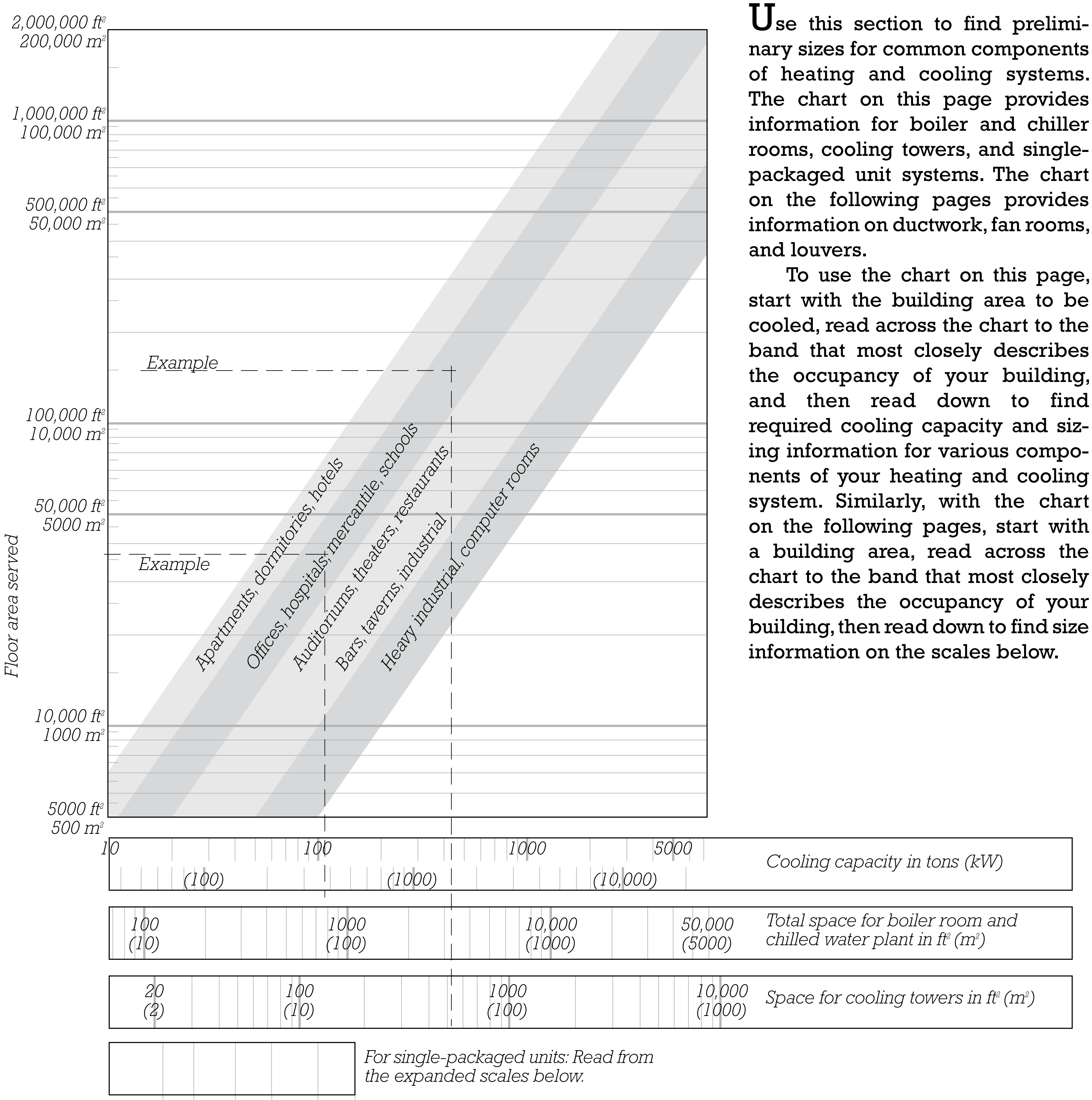


TYPICAL GRILLE AND DIFFUSER DESIGNS

HORIZONTAL DISTRIBUTION OF SERVICES FOR LARGE BUILDINGS

Use this section to find preliminary sizes for common components of heating and cooling systems. The chart on this page provides information for boiler and chiller rooms, cooling towers, and single-packaged unit systems. The chart on the following pages provides information on ductwork, fan rooms, and louvers.

To use the chart on this page, start with the building area to be cooled, read across the chart to the band that most closely describes the occupancy of your building, and then read down to find required cooling capacity and sizing information for various components of your heating and cooling system. Similarly, with the chart on the following pages, start with a building area, read across the chart to the band that most closely describes the occupancy of your building, then read down to find size information on the scales below.



Typical dimensions of single-packaged units in feet and inches (m)

11′–9″ (3.58)	11′–11″ (3.63)	17′–11″ (5.46)	25′–11″ (7.90)	41′–2″ (12.55)	61′–8″ (18.80)	Length
7′–2″ (2.18)		7′–2″ (2.18)	7′–4″ (2.33)	7′–8″ (2.34)	11′–10″ (3.61)	Width
4′–0″ (1.22)		7′–4″ (2.33)		7′–6″ (2.29)	8′–2″ (2.49)	Height

COOLING LOADS AND COOLING AIR VOLUMES FOR BUILDING TYPES

The chart on this page is based on the estimated cooling loads shown in the following table. Note that higher values in the table represent lower cooling loads. (The larger the figure, the greater the building area conditioned with one unit of cooling energy.)

If you are designing a high-performance building with the goal of reduced energy consumption, there are several ways you can use the chart to provide sizing information reflecting your design parameters.

1. You have established a goal for a percent reduction in cooling loads: For example, by reducing loads from equipment, lighting, the building skin, and other features, you plan to reduce cooling loads by 30%. To use the adjacent chart, read from it as you normally would to find an estimated *Cooling capacity required* (in tons or kW) on the first scale below the graph. Then, reduce that load to reflect your savings goal. For example, if reading from the graph produces an estimated cooling capacity of 1000 tons, you would reduce that figure by 30% to arrive at 700 tons (1000 × 0.70 = 700). As you read the scales below the cooling capacity scale, read downward from 700 tons instead of 1000 tons.

2. You have established a total cooling load budget for your project: Using modeling techniques, you have made a preliminary estimate of the total cooling load in your building. In this case, find that cooling load value on the *Cooling capacity required* scale, and then proceed downward from that value to read from the subsequent scales.

3. You have established a cooling budget related to square feet per ton or square meters per kilowatt: For example, you have made a preliminary cooling load estimate of 500 sq ft/ton in your office building design. By inspecting the preceding table, *Estimated Cooling Loads for Building Types*, you see that 500 sf/ton falls toward the high-demand range of average residential cooling loads. You then use the chart, but reading in the right-hand portion of the *Apartments. . .* band rather than from the *Offices. . .* band as you would for a building with average loads.

When reading the chart on the following pages, the same reductions taken on the chart on this page should be applied to that chart as well. For example, if you reduced cooling loads by 30%, you should reduce *Cooling air volume* by the same percentage and read from the lower scales on the chart accordingly.

ESTIMATED COOLING LOADS FOR BUILDING TYPES

Space Type	Minimum Cooling Load	Maximum Cooling Load
Residential	700 sq ft/ton (18 m^2/kW)	450 sq ft/ton (12 m^2/kW)
Business	450 sq ft/ton (12 m^2/kW)	250 sq ft/ton (6.5 m^2/kW)
Assembly, Industrial	250 sq ft/ton (6.5 m^2/kW)	100 sq ft/ton (2.6 m^2/kW)
Heavy Industrial, Computer Rooms	100 sq ft/ton (2.6 m^2/kW)	50 sq ft/ton (1.3 m^2/kW)

AN EXAMPLE OF THE USE OF THESE CHARTS

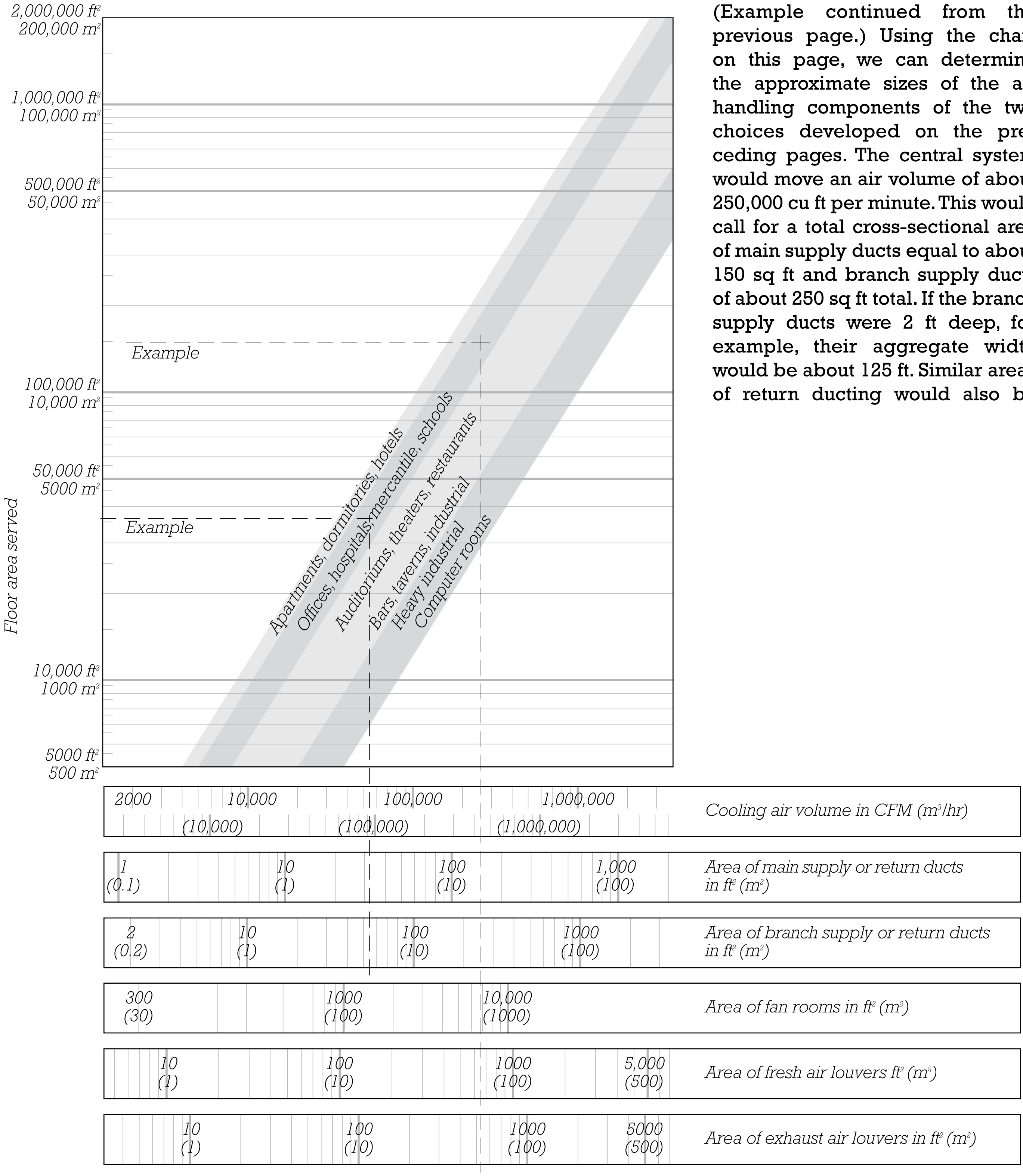
The Problem: Rough out the necessary spaces for VAV heating and cooling equipment for a department store with a total net floor area of 150,000 sq ft.

The Solution: Beginning with the chart on this page, we read horizontally from a floor area of 150,000 sq ft to the center of the diagonal band for Mercantile occupancies. (Notice that both the vertical and horizontal scales for this chart are logarithmic: 150,000 lies closer to 200,000 than to 100,000.) Reading down, we find that the required cooling capacity for this building is approximately 425 tons, requiring a chilled water plant and a boiler room that together will occupy an area of approximately 3250 sq ft. Cooling towers will occupy about 690 sq ft on the roof or alongside the building. The width of the diagonal band from which we have read gives us a range of roughly 325 to 600 tons for the cooling requirement, so we know that these space requirements may grow somewhat smaller or larger as the system is designed in detail.

These values assume a central plant for heating and cooling. Could rooftop single-packaged units be used instead? We see at the bottom of the chart that no single-packaged unit is large enough to handle the entire load. Starting from the largest available packaged unit and reading up, we intersect the diagonal band and read to the left to find that the unit could serve about 50,000 sq ft of this building. Four such units could be distributed about the roof to furnish heating and air conditioning for the entire building, each serving 37,500 sq ft. Each unit would need a capacity of about 125 tons and would measure 61 ft 8 in. long, 11 ft 10 in. wide, and 8 ft 2 in. high. A larger number of smaller units could also be used.

For more detailed information on boiler rooms, see page 186. Chilled water plants and cooling towers are explained on page 187 and single-packaged units on page 192.

Move to the following page to continue this example.



(Example continued from the previous page.) Using the chart on this page, we can determine the approximate sizes of the air handling components of the two choices developed on the preceding pages. The central system would move an air volume of about 250,000 cu ft per minute. This would call for a total cross-sectional area of main supply ducts equal to about 150 sq ft and branch supply ducts of about 250 sq ft total. If the branch supply ducts were 2 ft deep, for example, their aggregate width would be about 125 ft. Similar areas of return ducting would also be needed. Reading from the last three scales, we further determine that fan rooms totaling almost 7000 sq ft are needed, served by fresh air louvers adding up to about 650 sq ft in area and exhaust air louvers totaling nearly 525 sq ft. The location and distribution of this louver area on the outside surfaces of the building are of obvious architectural importance.

Each of the rooftop single-packaged units would need about 35 sq ft of main duct for supply air and the same for return, with a total area of 55 sq ft for branch ducts. Fans and louvers are incorporated into the units and do not need to be provided separately.

For further information on fan rooms and louvers, see pages 191–192.

3
PASSIVE HEATING AND COOLING SYSTEMS

This chapter will help you select and design passive heating and cooling systems for small and medium-sized buildings appropriate to your project's climate zone and building type.

PASSIVE HEATING AND COOLING DESIGN

Passive heating and cooling rely on natural systems to maintain a comfortable interior environment for building occupants. Solar radiation may be used as a source of heat for warmth. Naturally driven air currents can cool bodies directly or transport volumes of air at different temperatures into or out of a building. The thermal capacity of building materials can be exploited to lessen temperature extremes or store thermal energy for later reuse. The evaporation of water can be used to cool and humidify hot, dry air.

By reducing reliance on active systems powered by fossil fuels or electricity, passive systems reduce building energy consumption and the production of greenhouse gases. They rely on a minimum number of moving parts and are simple to maintain. They can also provide building occupants with the pleasure of a closer connection to the natural environment.

Passive heating and cooling strategies are best suited to small and medium-sized buildings and, in particular, those in which building form, orientation, and interior configuration can be molded to the requirements of these systems, as explained in more detail on the following pages. Large buildings, especially those with a high ratio of interior volume to exterior wall and roof area, are generally better suited to conventional mechanically driven heating and cooling systems. Conventional active systems are also generally a better choice where:

- Precise control over air temperature or humidity is required.
- Air quality must be strictly controlled.
- Interior spaces must be acoustically and visually isolated from each other and from their surroundings.
- Heating or cooling loads are high or highly variable.

PASSIVE DESIGN STRATEGIES

On the following pages, you will find preliminary guidelines for selecting and designing passive heating and cooling systems suitable to various building types and climates. For any passive design, also consider the following simple strategies to take maximum advantage of the natural environment and minimize building energy consumption.

Cold Climates

Protect against the cold winter winds:

- Avoid hilltops, north-facing slopes, narrow valley bottoms, and other locations exposed to concentrated or fast-moving winds.
- Identify the direction of prevailing winter winds, and take advantage of topography, planted barriers, or other natural or human-made features to shelter your building.
- Avoid large north-facing or windward-facing glass areas.
- Shape your building to shelter outdoor public spaces from winter winds.

Take advantage of the winter sun:

- Site and orient your building for good access to the winter sun. (See page 230 for more information.)
- Configure glazed openings to maximize the potential for winter solar heat gain.
- Use glazing with appropriate light transmittance and thermal performance characteristics.
- Use building materials with high heat capacity to store the sun's warmth during the day and release it back into the interior during cooler nights.

Minimize heat loss through the building enclosure:

- Consider compact building forms that reduce the area of the building enclosure in relation to its volume.
- Arrange secondary-use spaces (utility rooms, etc.) within the building to act as buffers to its colder north-facing or windward sides.
- Design and detail the building enclosure to minimize heat loss and air leakage.

Hot Climates

Exploit the prevailing summer winds:

- Site and orient your building to take advantage of natural ventilation. (See page 232 for more information.)
- Use amply sized, well-placed exterior openings and open interior plans to promote natural ventilation within the building.

Protect against the summer sun:

- Use trees and other vegetation to shelter the building from the summer sun.
- Design building overhangs and exterior shades to block the entry of the summer sun.
- Avoid overexposure to low early- and late-day sun.
- Avoid unshaded large east- and west-facing glazed areas.
- Use glazing materials with appropriate shading and thermal performance characteristics.
- Use exterior light-colored or reflective materials with care to avoid reflecting glare or heat into the building.
- Use building forms or groupings to create strategically shaded exterior public areas.

Reduce internal building heat loads:

- Use high-efficiency lighting and equipment that minimize heat production.
- Use natural daylighting to reduce the demand for light from electric sources. (See pages 142–149 for more information.)
- In buildings dominated by heat transfer through the building skin, design and detail the building enclosure to minimize heat gains and air leakage.

Mitigate very dry or very humid air:

- In dry climates, take advantage of natural or human-made water features to raise the relative humidity.
- In humid climates, consider raising the building to avoid the most humid air close to the ground.
- In humid climates, avoid increasing humidity with water features or extensive vegetated areas.

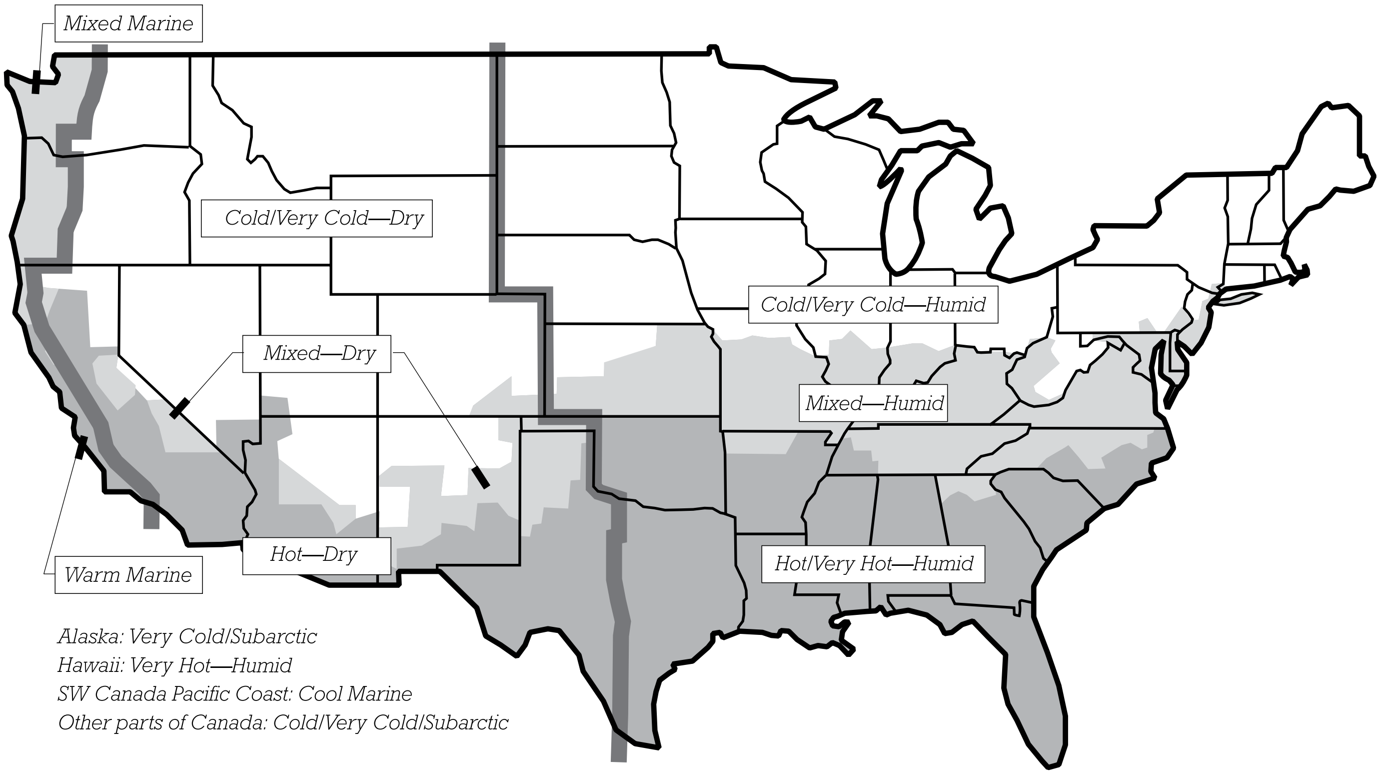
The successful performance of passive systems is dependent on the intimate interaction of the building with its environment. As your design work progresses, be sure to study further and analyze in greater detail the preliminary designs arrived at with the aid of this book.

SELECTING PASSIVE HEATING AND COOLING SYSTEMS

The choice of suitable passive heating and cooling systems depends on the climate in which the building is located. Extremes of temperature and humidity define the conditions under which a building must remain comfortable to its occupants. Climatic conditions also define the resources available to the passive systems designer. For example, in a hot, dry climate with large temperature swings from day to night, cool nighttime air can be circulated through the building to extract heat generated during the day. Or, in a hot location with reliable prevailing winds, comfortable interior conditions may be maintained with cross ventilation through the building during daytime work hours.

The *Climate Zones* map on this page identifies major climate regions in the continental United States and other parts of North America. Note how the 48-state region is generally divided into humidity zones from west to east—*Marine*, *Dry*, and *Humid*—and temperature zones from north to south—*Cold*, *Mixed*, and *Hot*. Use this map to identify the climate zone in which your building is located.

Next, use the table labeled *Passive Heating and Cooling Systems* to identify strategies best suited to your project's climate. In cold climates, passive heating should be the primary design consideration, and in hot climates, passive cooling. Systems meeting these criteria are marked as *Most Suitable* in the table. For example, in a cold/dry climate, winter heating should be the primary concern, and solar heating is indicated. In hot climates, appropriate cooling strategies are identified in the same way, and in mixed-temperature climates, both appropriate heating and cooling strategies are indicated. To learn more about these systems, see the pages referenced in the table.



Alaska: Very Cold/Subarctic
Hawaii: Very Hot—Humid
SW Canada Pacific Coast: Cool Marine
Other parts of Canada: Cold/Very Cold/Subarctic

CLIMATE ZONES

Other systems are marked as *Suitability Varies*. These may be considered for off-peak season conditioning, such as summer cooling in a primarily cold climate or winter heating in a primarily hot climate. In some cases, the appropriateness of these systems may also depend on more detailed climate specifics. See the chart below and the following pages.

PASSIVE HEATING AND COOLING SYSTEMS

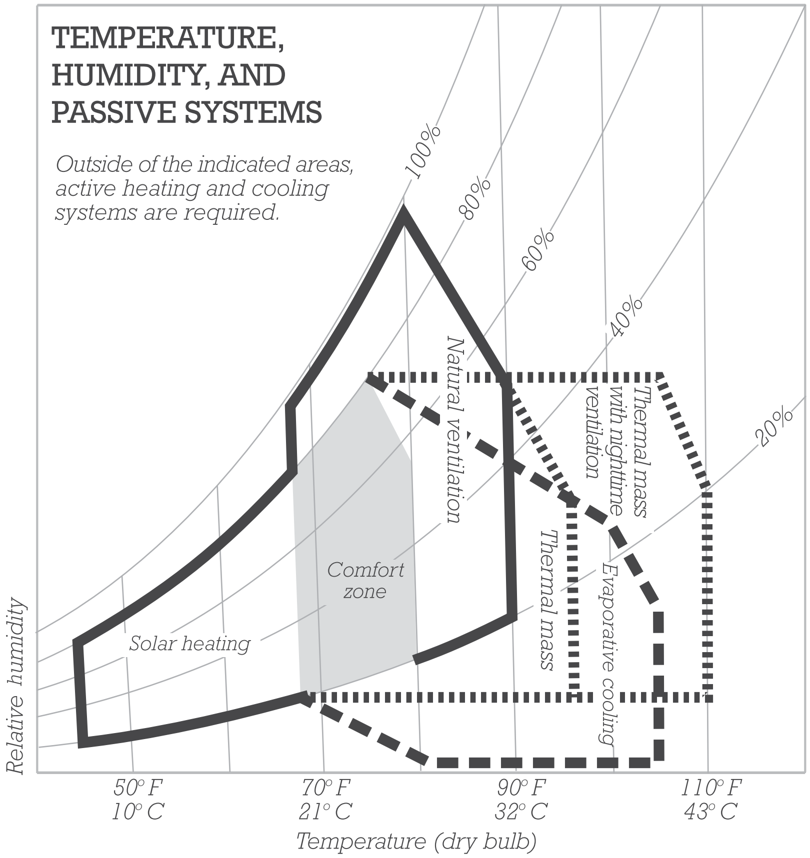
	Heating	Cooling				
Climate Zone	**Solar Heating Pages 228–230**	**Cross Ventilation Cooling Pages 231–233**	**Stack Ventilation Cooling Pages 231–233**	**Thermal Mass Cooling Pages 234–236**	**Thermal Mass with Nighttime Ventilation Pages 234–236**	**Evaporative Cooling Pages 237–238**
Cold-Humid	●	O	O			
Cold-Dry	●	O	O	O		O
Mixed-Humid	●	●	●			
Mixed-Dry	●	●	●	●	O	O
Mixed-Marine	●	●	●	O		
Hot-Humid	O	●	●			
Hot-Dry	O	●	●	●	●	●
Warm-Marine	O	●	●	O		

●: Most suitable

O: Suitability varies (see text)

SELECTING PASSIVE HEATING AND COOLING SYSTEMS

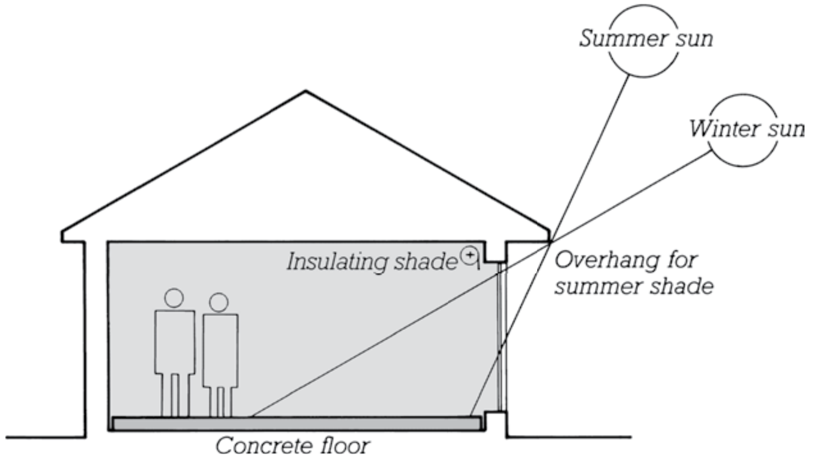
Where more detailed ambient temperature and humidity data is available, use the chart at right to identify the systems most appropriate to your project. As project conditions approach or fall beyond the limits of the ranges indicated, active heating and cooling systems will be required. However, even when active systems are used, passive systems can in many instances still make a significant contribution to the cooling or heating requirements of a building and to a reduction in the building's reliance on fossil fuels or electricity.



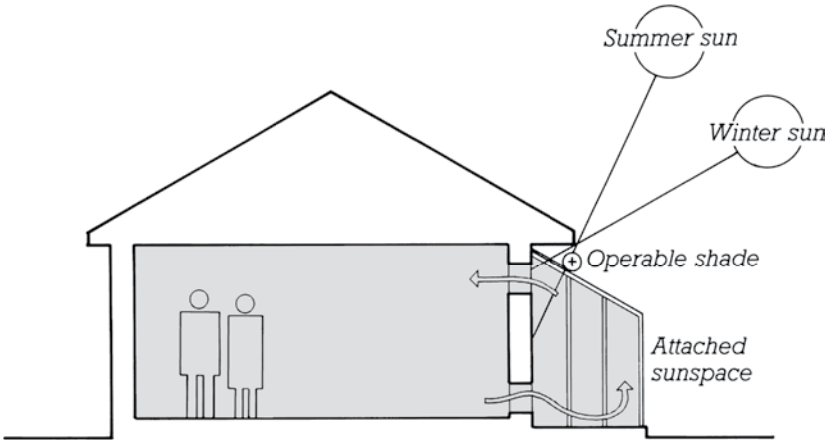
(Based on Grondzik and Kwok, 2018.)

Description

The interior space of the building acts as a solar collector, receiving sunlight directly through large south-facing windows and storing excess heat in thermal mass materials such as concrete, masonry, adobe, rammed earth, water, or phase-change salts. During sunless periods, a comfortable temperature is maintained as stored heat is released back into the space. Roof overhangs or exterior shading devices are configured to block out high summer sun when heat gain is not desirable. In colder climates, insulating shutters or curtains and high-performance glazing materials should be used to reduce heat losses through the large glass areas during cloudy days and nights.



DIRECT GAIN PASSIVE SOLAR HEATING



ATTACHED SUNSPACE PASSIVE SOLAR HEATING

Typical Applications

Passive solar heating is suitable for small buildings in which heat loss through the building skin is the predominant winter design condition. This includes dwellings, schools, offices, and other low-rise buildings not dominated by internal heat gains.

Advantages

Passive solar heating has no operational costs, consumes no energy, requires little or no maintenance, and can be aesthetically satisfying.

Disadvantages

Except in mild climates, a backup heating system must be provided to heat the building during long sunless periods. Relatively large swings in interior temperature must be expected. Building occupants may be required to perform daily control duties such as opening and closing insulating shutters or curtains. The architecture of solar-heated buildings is strongly influenced by the need to orient and configure the building for optimum solar collection. Where floors, walls, or ceilings are used as thermal mass, these surfaces must not be covered with carpets, wall hangings, or other materials that thermally insulate the mass from the interior. Cooling and humidity control must be accomplished with separate systems.

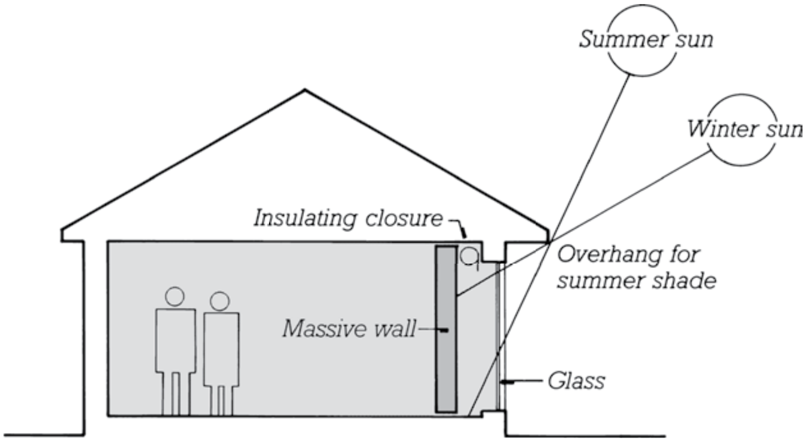
Variations

1. In *direct gain solar heating*, sunlight enters south-facing windows, warming the interior directly. Thermal mass materials are located within the heated spaces. For maximum effectiveness, these materials should be situated in the path of direct sunlight. Direct gain solar heating is a simple, enjoyable way of bringing heat into a building, one that places the occupants in an intimate relationship with the seasons and the weather. However, direct sunlight causes visual glare, and it fades and deteriorates interior materials. Heat loss through the large glass areas during nights and cloudy days may be considerable.

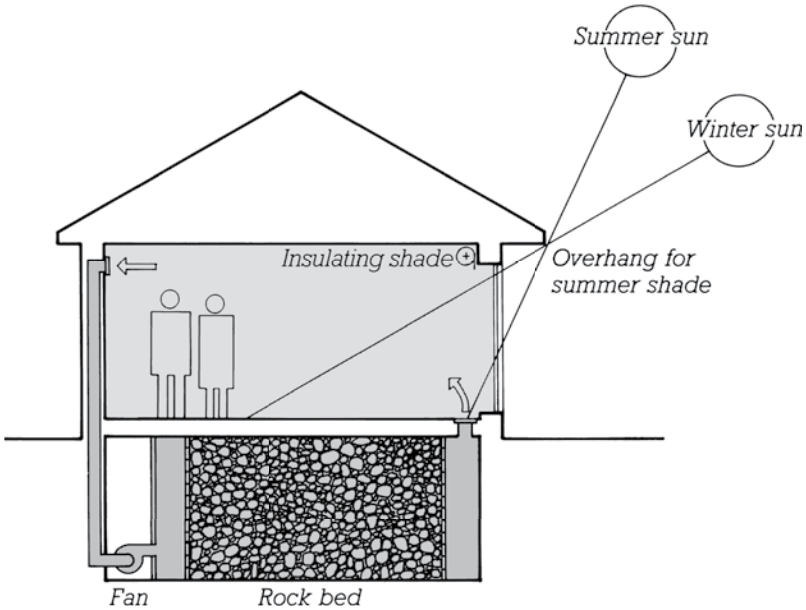
2. In *attached sunspace solar heating*, a greenhouse, glassy atrium, or glazed circulation corridor attached to the building collects solar heat by direct gain. Heated air is shared with adjacent spaces by means of natural convection or small, powered fans. Undesirable glare and fading are largely confined to the sunspace. The sunspace can be closed off during sunless periods and allowed to grow cold, reducing building heat losses during such periods. The sunspace will undergo large, often uncomfortable temperature fluctuations. Thermal mass walls and floors within the sunspace can, to some extent, moderate temperature swings. But unless additional active control mechanisms are provided, such spaces are typically unsuitable for growing plants or regular occupancy. Attached sunspace solar heating is generally the least efficient of the passive solar heating methods discussed in this section.

3. *Trombe wall solar heating* features thermal mass walls located immediately inside the windows that receive sunlight. The interior of the building is warmed by heat conducted through the walls, by allowing room air to convect between the wall and the glass, or both. Compared to direct gain solar heating, a Trombe wall system blocks a significant portion of the direct sunlight from the inhabited space, preventing glare and fading of materials. The wall occupies considerable space, however, and limits outdoor views.

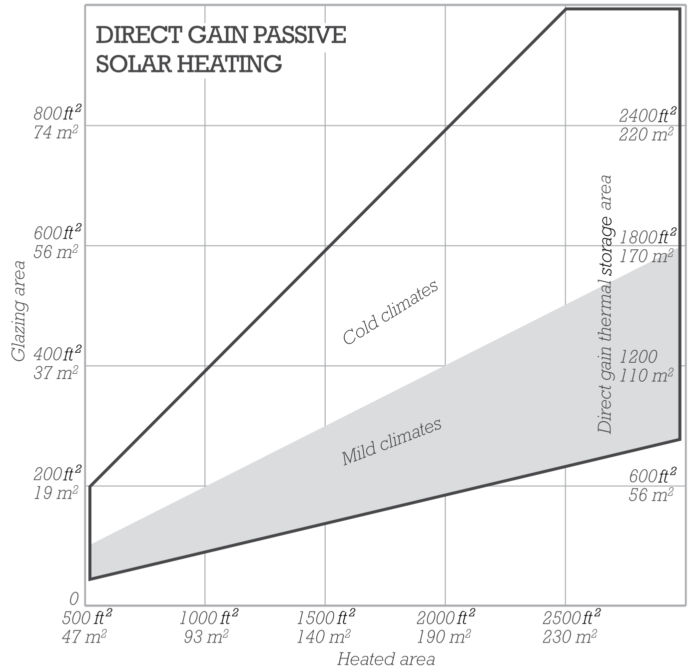
4. *Fan-forced rock bed solar heating* is a hybrid of passive and active systems. Sunlight is brought directly into the inhabited spaces of the building. When the interior air temperature rises above the comfort level, thermostat-controlled fans draw the overheated air through a large container of stones, where the excess heat is absorbed. During sunless periods when the interior air temperature drops, the fan is actuated again to warm the room air by passing it through the heated stones. Compared to direct gain and Trombe wall solar heating, a fan-forced rock bed system gives better control of temperature and does not require the presence of massive materials within inhabited spaces. However, the rock bed is large and expensive to construct. Glare and fading are problems unless the system is coupled with an attached sunspace.



TROMBE WALL PASSIVE SOLAR HEATING



FAN-FORCED ROCK BED PASSIVE SOLAR HEATING

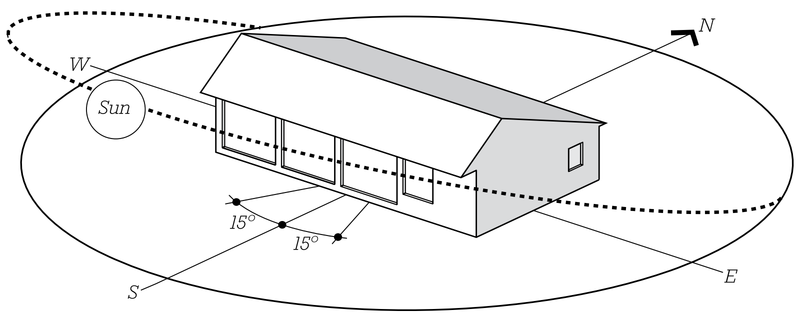


Design

Passive solar buildings should be sited for maximum solar gain potential. Avoid locations shaded in the heating season by topography, vegetation, or human-made structures. Maximum solar gains are achieved when a building's collecting surfaces are oriented within 15 degrees of true south. However, even buildings oriented as much as 45 degrees away from south can still achieve some benefit. For more information on the path of the sun, see page 144.

Orient the long axis of the building east–west and, in the northern hemisphere, locate the most important interior spaces along the south side of the building. Locate utility rooms, bathrooms, and other secondary-use spaces along the north side of the building, where they can serve as heat loss buffers to this colder side. Use external shading devices to prevent undesirable gains from the high summer sun. Avoid unshaded large east- and west-facing glass areas that may make interior spaces prone to overheating.

For direct gain and Trombe wall systems, locate thermal mass surfaces in direct line of sight with occupants, allowing the benefit of thermal radiation from these surfaces.



PASSIVE SOLAR BUILDING ORIENTATION

Sizing Passive Solar Heating Systems

Use the chart on this page to determine south-facing glazing and internal mass requirements for passive solar heating systems. Read higher in the chart ranges for buildings in areas with limited solar access; read lower in the ranges for well-insulated buildings. In most climates, a backup heating system must also be provided.

- For direct gain systems, read the glazing area and thermal storage area directly from the chart. For designs relying on passive solar energy for a large portion of the building's total heating needs, increase the indicated thermal storage area by as much as a factor of 2. For water or phase-change salts, the indicated thermal mass area may be reduced by as much as a factor of 3.

- For attached sunspace heating, read the glazing area directly from the chart. Thermal mass, if used, will be limited in area by the extent of the sunspace.

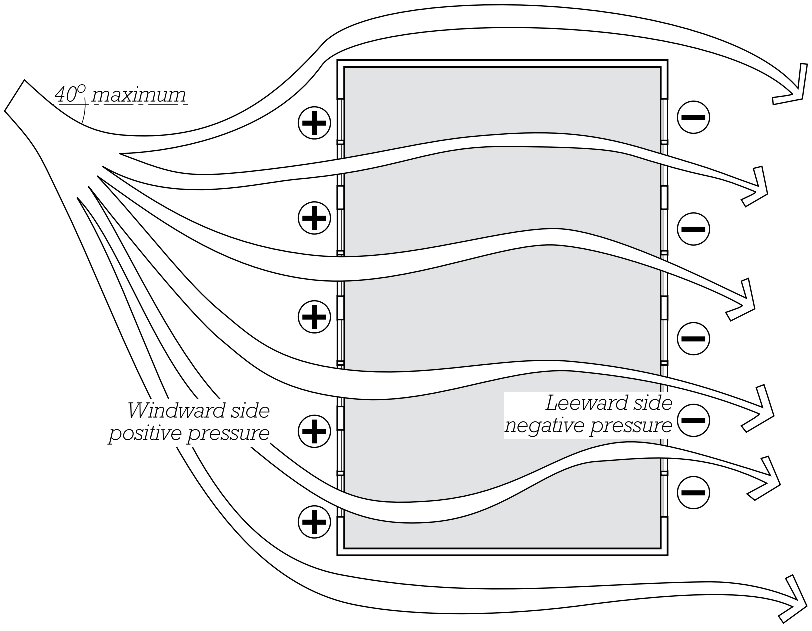
- For Trombe wall heating, read the glazing area directly from the chart. For designs relying on passive solar energy for a large portion of the building's total heating needs, increase the recommended glazing area by as much as a factor of 1.5. The area of mass walls is equal to the glazing area. They are typically 6 to 16 in. (150 to 400 mm) thick and spaced 1 to 24 in. (25 to 300 mm) from the adjacent windows. Use a thinner wall where heating needs are more immediate during the day; use a thicker wall where heating needs are delayed until evening or night.

- For fan-forced rock bed heating, read the glazing area directly from the chart. Provide 0.5–0.75 cu ft of rock storage per square foot of glazing (0.15–0.22 m^3 of rock per square meter of glazing). For example, with 400 sq ft (37 m^2) of south-facing glazing, provide 200–300 cu ft (5.6–8.1 m^3) of rock storage.

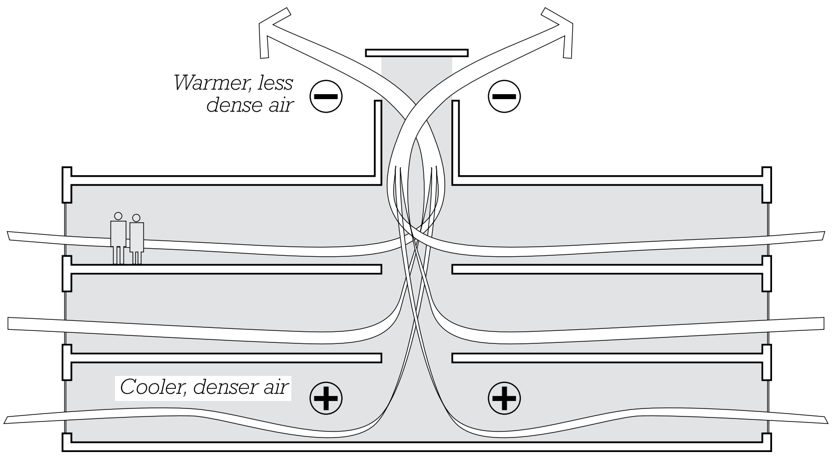
NATURAL VENTILATION COOLING

Description

Outside air circulates through the building during occupied hours. Occupant comfort is improved by the direct cooling effect of the moving air. As air passes through the building, excess heat is flushed to the exterior.



CROSS VENTILATION (PLAN VIEW)



STACK VENTILATION (SECTION VIEW)

Typical Applications

Natural ventilation cooling is adaptable to most climate types where cooling is required. It is an especially good choice for humid climates where other passive cooling strategies are less effective. This type of cooling is best suited to small and medium-sized buildings. It is not frequently employed in tall buildings, where the large air pressure differentials that develop across the faces of such buildings make regulation of naturally driven airflows difficult.

Advantages

Natural ventilation cooling is a passive strategy with no significant operational costs, energy consumption, or maintenance needs.

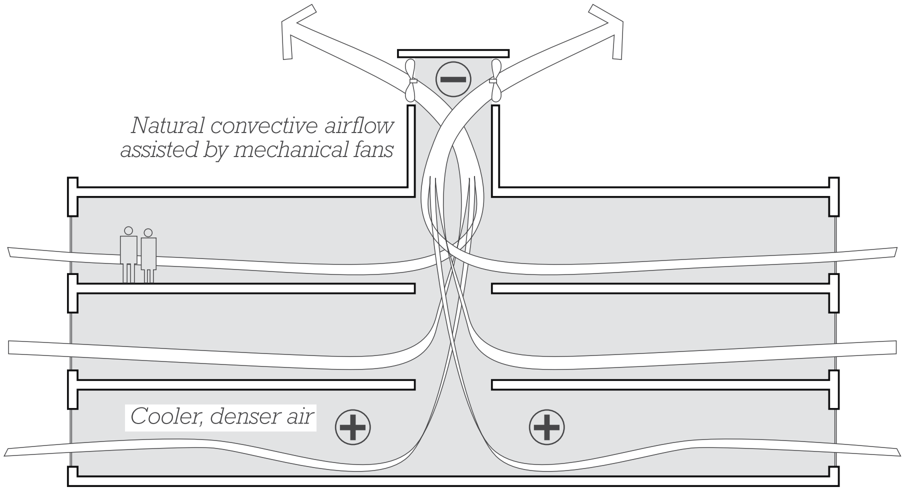
Disadvantages

Natural ventilation strategies rely on large exterior openings, open floor plans, and, in some cases, interconnected floor levels. These may conflict with program requirements, visual or acoustic privacy needs, or fire-safety regulations requiring compartmentalization of spaces. Precise control of interior air temperature, humidity, and air pollutants is not possible. The necessary exterior openings may admit unwanted outside noise into the building.

Variations

1. *Cross ventilation* relies on wind forces to move air through the building. Passage of the wind creates areas of higher and lower air pressure on different parts of the building exterior. With appropriately arranged exterior openings, these pressure differences can be exploited to move outside air through the interior. This strategy requires building locations exposed to reliable prevailing winds during the cooling season.

2. *Stack ventilation* relies on convective pressures (the natural buoyancy of warmer air compared to cooler air) to move air through the building. As interior air gains heat, it rises and then is exhausted from openings located high in the building, while cooler outside air is drawn in lower down. Stack ventilation is an effective alternative to cross ventilation where prevailing winds are weak or unpredictable. However, stack ventilation requires structures of sufficient height to produce the necessary convective forces.



MECHANICALLY ASSISTED NATURAL VENTILATION

3. *Mechanically assisted natural ventilation cooling* uses powered fans to increase airflows through the building when prevailing winds or stack pressures are insufficient to meet the air movement and cooling needs of the building's occupants.

Design

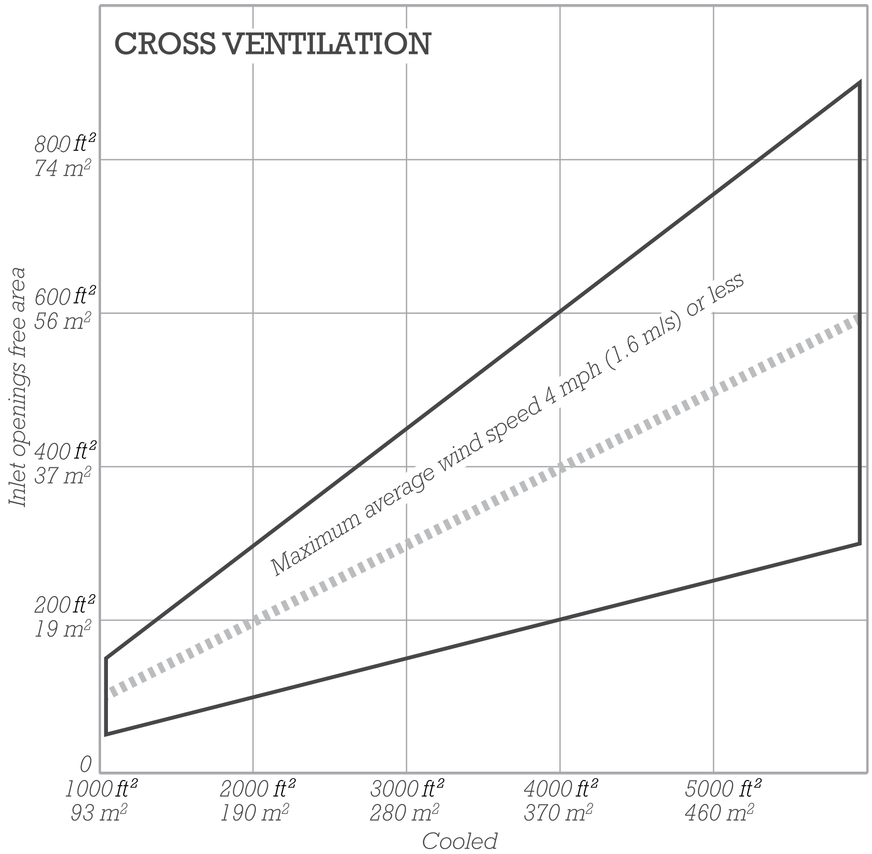
Cross-ventilation cooling depends on the availability of consistent winds during the building's cooling season operating hours. Local wind data can be obtained from a variety of sources, including those listed in this book's bibliography. Such data, often obtained at airport or other open field locations, should be adjusted to reflect local site conditions. For example, average wind speeds in dense urban areas may be as much as one-half of those recorded for open areas. Wind shadows from adjacent structures, the channeling of wind in narrow valleys or urban canyons, the acceleration of wind over bodies of water, and other localized effects on wind speed and direction should also be considered.

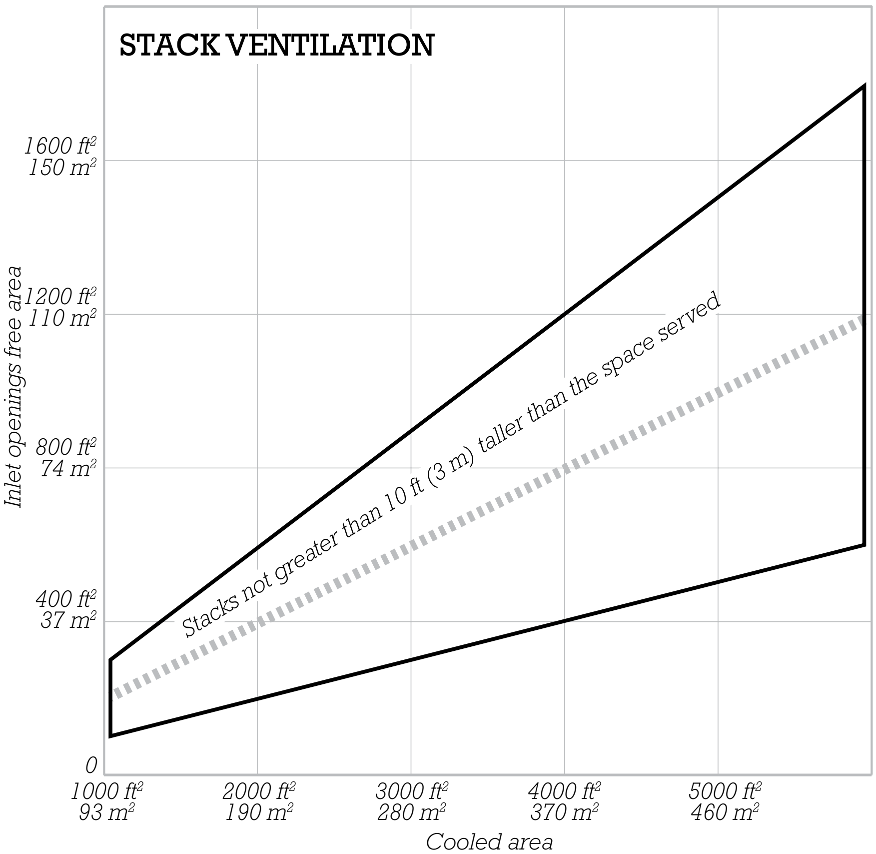
Cross-ventilated buildings and their openings should be oriented to exploit the prevailing winds. For buildings rectangular in plan, the longer side should be oriented roughly perpendicular to the direction of the wind or at an angle of not more than 40 degrees from this direction. Exterior openings should be divided between areas of positive pressure (windward exposure) and negative pressure (leeward exposure). The combined area of the leeward openings should be at least as great as that of the windward openings. Where prevailing winds are reliable in strength but not direction, openings should be arranged in multiple orientations so that they work effectively with winds from any expected direction.

Stack ventilation depends on stack height to generate the convective pressures that move air through the building. Stack effectiveness can also be enhanced with wind-induced negative pressures at the top of the stack, by solar heating of the portion of the stack above the building (a solar chimney), or with the aid of powered fans. When a stack serves multiple floor levels, it should be at least one-third to one-half as tall as the height of the levels served, so as to provide effective ventilation for the highest levels. Building orientation is generally not critical to successful stack ventilation, although care should be taken to ensure that where strong winds occur, they will not work at cross purposes to stack-induced pressures. The free area of the stack outlet openings and the stack itself should be at least as great as the area of the windows or other air inlet openings. Inlet openings and stacks should be arranged to balance airflow throughout ventilated areas and to avoid dead zones where air can stagnate.

Within any naturally ventilated building, air must be able to flow freely from inlet to outlet openings. Thus, the cross-sectional area of internal openings should be at least as great as the area of the exterior inlets, and these openings should be arranged to allow air to circulate throughout the areas to be cooled. Because circulation air gains heat as it moves through the building, occupants should be located close to air inlets where possible, and equipment or other items that generate heat should be located close to outlets. Within individual spaces, locating air inlets low and outlets high can exploit convective effects to enhance air movement and maximize heat extraction from the space.

As with any type of passive cooling design, building heat gains from both internal and external sources should be minimized. Solar heating should be controlled with shading strategies and the choice of appropriate glazing materials. Internal heat gains should be minimized with the selection of efficient lighting devices and equipment. Daylighting strategies should be employed where possible.





Sizing Natural Ventilation Systems

Use the top chart on this page to find the minimum total area of inlet openings for a cross-ventilated building. Read higher in the indicated areas for hotter climates, buildings with higher internal heat gains, or lower wind speeds. Read lower for cooler climates, buildings with lower internal heat gains, or higher wind speeds.

■ For building locations with average wind speeds of 4 mph (1.6 m/s) or less, read only above the dashed line indicated. For locations with faster winds, read in all areas indicated.

■ For openings with insect screening, double the indicated free area. For louvers or other partial opening obstructions, adjust the indicated area appropriately.

■ The combined area of outlet openings should be equal to or greater than the combined area of inlet openings.

Use the bottom chart on this page to find the combined minimum area of inlet openings for a stack-ventilated building. Read higher in the chart for hotter climates, buildings with higher internal heat gains, or shorter stacks. Read lower for cooler climates, buildings with lower internal heat gains, or taller stacks.

■ For openings with insect screening, double the indicated area.

■ For stacks not more than 10 ft (3 m) tall, read only above the dashed line indicated. For taller stacks, read in all areas indicated.

■ The combined cross-sectional area of stacks should be equal to or greater than the combined area of inlet openings serving the same area.

Description

During the day, thermal mass materials within the building absorb heat and moderate rising temperatures. During the night, the building is ventilated with cooler outside air, extracting the stored heat from the mass and flushing it to the exterior. Heavyweight structural systems such as concrete, masonry, rammed earth, or adobe serve as thermal mass.

Typical Applications

Thermal mass cooling is an effective strategy where outdoor temperature swings are high—20°F (11°C) or more—on an average daily basis. The most favorable conditions for thermal mass cooling occur in dry climates, such as in any of the U.S. dry climate zones shown on the map on p. 225. However, outside of coastal areas, minimally acceptable conditions for this strategy can be found throughout much of the continental United States.

During the day, when outside air temperatures are higher than those inside the building, all or most windows remain closed. Indoor air quality is maintained by some combination of mechanical ventilation and/or controlled use of operable openings. During the cooler nights, windows are opened and natural ventilation is used to circulate large volumes of air through the building, thereby removing the stored heat. Alternatively, nighttime ventilation can be provided mechanically, making thermal mass cooling applicable to a greater variety of building sizes and configurations than those adaptable to natural ventilation.

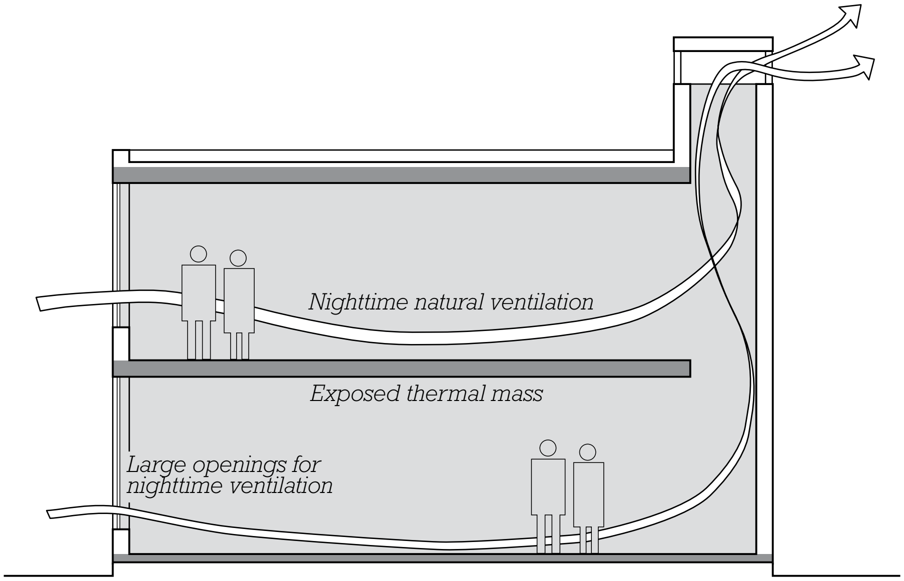
Advantages

Thermal mass cooling with nighttime natural ventilation is a passive strategy without significant operational costs, energy consumption, or maintenance needs. When ventilation is provided mechanically, energy costs are still low in comparison to those for conventional active building cooling systems. Where thermal mass cooling on its own cannot maintain comfortable interior temperatures, it can also work in conjunction with active systems.

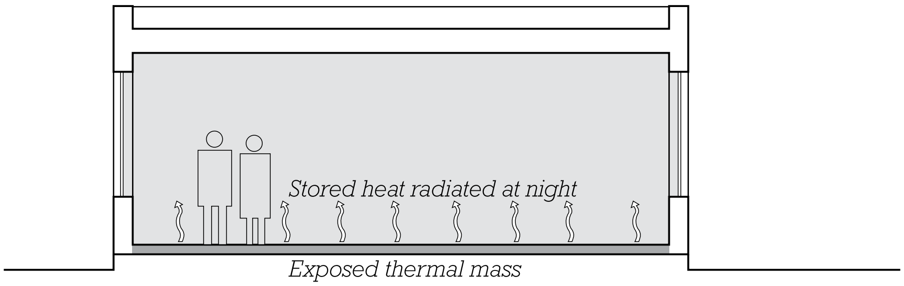
The same thermal mass used for summer cooling can be used for passive solar heating in climates where both strategies are appropriate.

Disadvantages

Thermal mass surfaces cannot be covered with carpeting, acoustic panels, or other materials that thermally insulate the mass from the interior air. Where nighttime ventilation is provided by natural means, humidity and air pollutants may be difficult to control, and the necessarily large exterior openings may create security or acoustic concerns. Natural ventilation strategies also rely on open floor plans and interconnected spaces that may conflict with programmatic requirements or regulations requiring compartmentalization of space for fire safety.



THERMAL MASS WITH NIGHTTIME VENTILATION



THERMAL MASS WITHOUT NIGHTTIME VENTILATION

THERMAL MASS COOLING

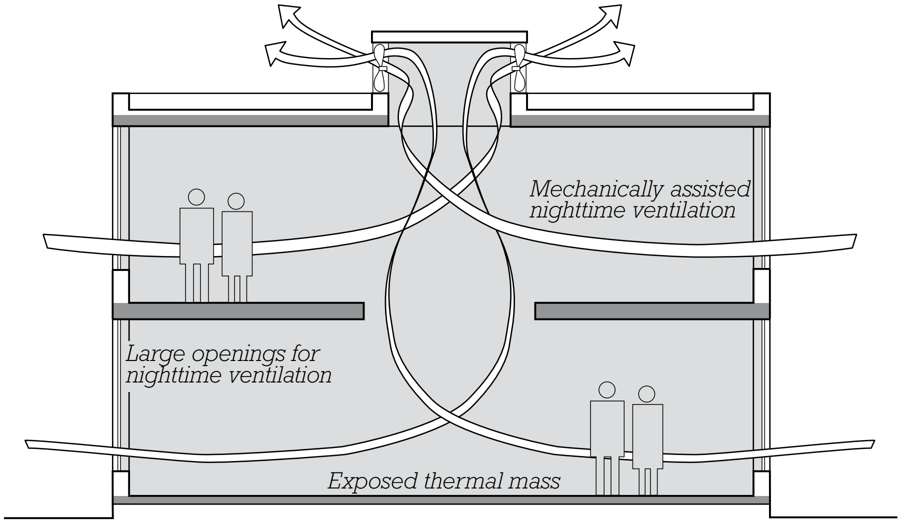
Variations

1. In *thermal mass with natural nighttime ventilation*, heat stored during the day by interior mass is flushed from the building at night, using natural ventilation strategies. Stack ventilation, which is not dependent on nighttime winds, may be preferred over cross ventilation. Open floor plans are required to ensure thorough flushing of the thermal mass surfaces. For more information on design for natural ventilation, see pages 231–233.

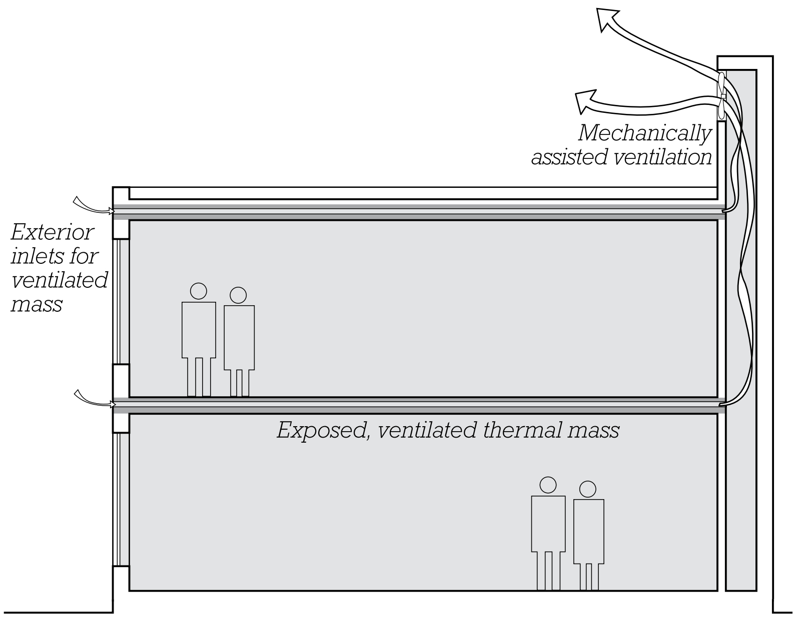
2. In *thermal mass without nighttime ventilation,* heat stored by building mass during hot days is released directly back into interior spaces during cooler nights. This strategy is most suitable for relatively small buildings located in cooler climates. The heat accumulated during the day either serves to keep the building comfortably warm during the night or is lost through the building skin without the aid of nighttime ventilation. See the chart on page 227 for conditions suitable to this strategy.

3. *Thermal mass with mechanically assisted nighttime ventilation* works similarly to variation 1. But the reliance on mechanical systems rather than natural ventilation to move nighttime air through the building makes this variation practical for a greater variety of building sizes and configurations.

4. *Thermal ventilated mass* is another mechanically assisted variation in which the thermal mass components are hollow, and nighttime air is drawn by fans directly through the mass components themselves rather than through the interior spaces of the building. Hollow core concrete planks (see pages 134–135) are one example of a structural component adaptable to this application. This variation reduces the need for open floor plans and large, operable exterior openings.



THERMAL MASS WITH MECHANICALLY ASSISTED NIGHTTIME VENTILATION



THERMAL VENTILATED MASS

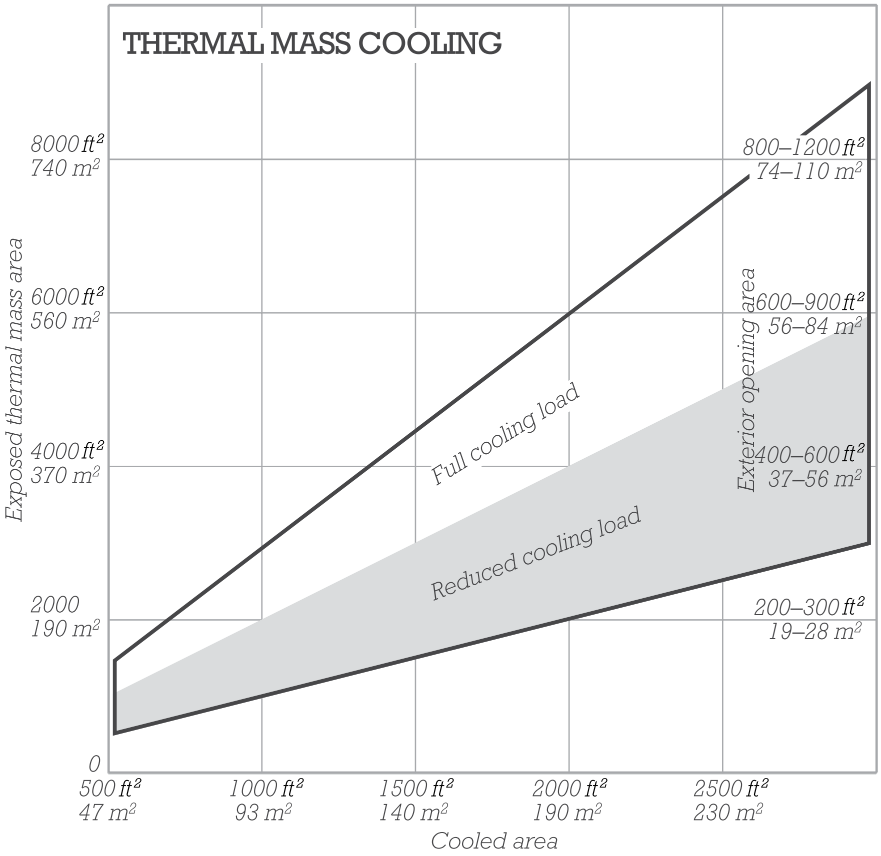
Design

The thermal mass surfaces must be located within the occupied areas of the building and must be situated in the direct path of the nighttime ventilation airflow. Where possible, these surfaces should be in the direct line of sight of building occupants, so that occupants may also benefit from radiant cooling effects.

Building thermal insulation must be positioned to the exterior side of the thermal mass. For buildings constructed of lighter-weight structural systems, special wallboard or other materials formulated with encapsulated phase-change materials may provide the needed thermal capacity.

For designs that rely on flushing of nighttime air through interior spaces (variations 1 and 3 above), these spaces must be sufficiently open and interconnected to permit unimpeded airflow. Where nighttime ventilation is provided by natural means, the building design guidelines for natural ventilation provided on page 232 should be followed. Note, however, that these two strategies, natural ventilation cooling (which occurs during the day) and thermal mass cooling with nighttime ventilation, cannot be used in the same building.

As with any type of passive cooling design, building heat gains from both internal and external sources should be minimized. Solar heating should be controlled with shading strategies and the choice of appropriate glazing materials. Internal heat gains should be minimized with the selection of efficient lighting devices and equipment. Daylighting strategies should be employed where possible.



Sizing Thermal Mass Cooling Systems

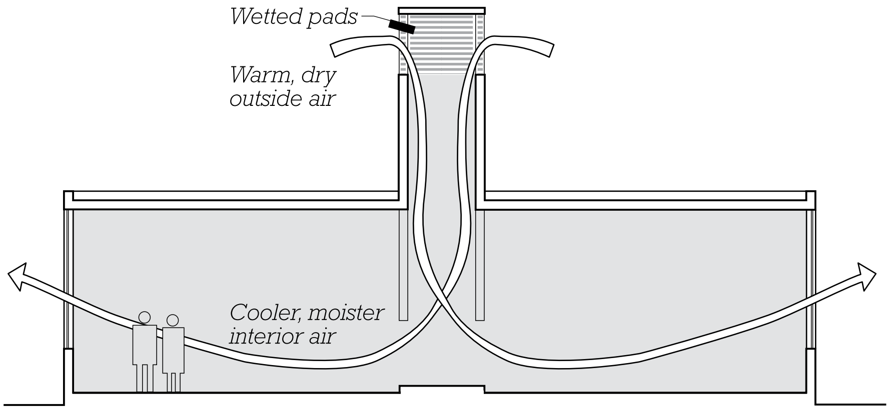
Use the chart on this page to determine the required areas for internal thermal mass and exterior openings for thermal mass cooling designs. Read higher in the indicated areas for hotter climates or for buildings with higher internal heat gains. Read lower in the chart for cooler climates or for buildings with lower internal heat gains.

- For thermal mass with natural nighttime ventilation, read exposed thermal mass and exterior opening areas from within the *Full cooling load* chart area.
- For thermal mass without nighttime ventilation, read exposed thermal mass areas anywhere within either the *Full* or *Reduced cooling load* chart areas.
- For thermal mass with mechanically assisted nighttime ventilation, read exposed thermal mass areas from the *Full cooling load* chart area. Reduce the indicated exterior opening area by one-half.
- For thermal ventilated mass, read exposed thermal mass from the *Full cooling load* chart area.

EVAPORATIVE COOLING

Description

Hot, dry outside air passes through wetted pads or misted water in cooling towers located above the occupied portions of a building. As the water evaporates, the air is cooled, and its relative humidity rises. This cooler, moister, and more comfortable air then descends and passes through the building interior.



EVAPORATIVE COOLING

Typical Applications

Evaporative cooling lowers the temperature of air and raises its moisture content. It is most appropriate for hot, dry climates (see the map on page 225) where adding moisture to air does not decrease comfort. Passive evaporative cooling relies on natural ventilation to distribute the conditioned air through the building, making it most suitable for small and medium-sized buildings.

Appropriate conditions for evaporative cooling are represented graphically on the *Temperature, Humidity, and Passive Systems* chart on page 227. Where additional local climate data are available, consider passive evaporative cooling where average exterior *wet bulb* temperatures do not exceed 68 to 70°F (20 to 21°C) at the hottest time of the year.

Advantages

Evaporative cooling does not depend on the wind, making it a possible alternative where natural ventilation is not practical. Evaporative cooling systems consume far less energy than conventional refrigeration cycle equipment, requiring only small amounts of power to supply water to the tower. Evaporative coolers do not use environmentally hazardous refrigerants.

Disadvantages

Evaporative cooling depends on the cooling effect of water evaporation. It is not effective in humid climates, where adding water to the air would serve mainly to increase the relative humidity that is already uncomfortably high, but would do little to lower air temperature. Evaporative cooling systems consume water. They may not be appropriate for arid areas where water supplies are restricted. The very damp portions of the system may introduce odors into the supply air stream and have the potential to foster biological growth. Periodic inspection and cleaning may be required.

Variations

1. *Passive evaporative cool towers* extend above the roof level of the building. Outside air is drawn into the top of the towers, where it passes through pads kept continuously damp, or through a continuous water mist. As the air is cooled and humidified by water evaporation, it becomes more dense and descends into the building. No fans are required to move the air.

2. *Small mechanical evaporative coolers* are packaged units that use powered fans rather than natural convective forces to move evaporative cooled air through the units and into the building. They are suitable for small buildings. For more information on coolers of this type, see page 253.

3. *Larger mechanical evaporative coolers* are more sophisticated packaged units that can be incorporated into conventional ducted HVAC systems. In appropriate climates, these units can replace or supplement refrigeration-based cooling equipment, reducing cooling costs and energy consumption. *Indirect* mechanical evaporative coolers use a heat exchanger to cool interior air without introducing additional moisture, expanding somewhat the range of climate conditions under which these units can be used. For more information on the use of packaged cooling equipment in larger buildings, see pages 192–194.

Design

A natural downdraft is created in the cool tower as warm outside air enters the tower, is cooled and humidified, and increases in density. As this more comfortable air descends into the building, warmed interior air is displaced and exhausted through remote windows or other openings. In fact, cool towers function essentially as the reverse of stack ventilation, and these towers are sometimes called *reverse chimneys*.

Passive evaporative cooling relies on natural ventilation to distribute conditioned air throughout the building. Wind or stack pressures are not required, as the pressure to move building air comes from the descending heavier air in the tower itself. The building interior must be sufficiently open to allow efficient movement of air, and exterior openings of sufficient size and appropriate distribution must be provided to act as air outlets. Cool towers can also be combined with stack ventilation, with the cool towers acting as air inlets and other ventilation stacks acting as outlets. Use the guidelines on page 232 for the design of natural ventilation aspects of the system.

As with any type of passive cooling design, building heat gains from both internal and external sources should be minimized. Solar heating should be controlled with shading strategies and the choice of appropriate glazing materials. Internal heat gains should be minimized with the selection of efficient lighting devices and equipment. Daylighting strategies should be employed where possible.

SIZING COOL TOWERS

The required height of the cool tower and the area of cooling media (wetted pads) depend on the exterior temperature and humidity, the internal cooling load, and the building area to be served. Use the table on this page as a guide for preliminary cool tower selection. Use taller, larger-dimension towers in hotter, more humid climates and in buildings with higher internal cooling loads. Use smaller, shorter towers where requirements are less severe.

In the following table, the *Smaller-Dimension Cool Tower* is assumed to have a cooling media area of 32 sq ft (3.0 m^2), and the *Larger-Dimension Cool Tower* to have a cooling media area of 48 sq ft (4.5 m^2). Practical dimensions for the tower itself range from 10 to 40 ft (3.0 to 12 m) in height and approximately 5 to 12 ft (1500 to 3600 mm) on each side. Tower height is measured from where air enters the tower to where it exits.

TYPICAL COOL TOWER SIZES

			BUILDINGS WITH LOW COOLING LOAD		**BUILDINGS WITH MEDIUM COOLING LOAD**	
Exterior Temperature	**Exterior Relative Humidity**	**Building Area to Be Cooled**	**Height of Smaller-Dimension Cool Tower**	**Height of Larger-Dimension Cool Tower**	**Height of Smaller-Dimension Cool Tower**	**Height of Larger-Dimension Cool Tower**
90°F (32°C)	23%	1500 ft^2 (140 m^2)	15′ (4.6 m)		20′ (6.1 m)	
90°F (32°C)	18%	1500 ft^2 (140 m^2)	10′ (3 m)		15′ (4.6 m)	
105°F (41°C)	15%	1500 ft^2 (140 m^2)	10′ (3 m)		15′ (4.6 m)	
90°F (32°C)	23%	3000 ft^2 (280 m^2)		20′ (6.1 m)		35′ (11 m)
90°F (32°C)	18%	3000 ft^2 (280 m^2)	40′ (12 m)			30′ (9 m)
105°F (41°C)	15%	3000 ft^2 (280 m^2)	35′ (11 m)			25′ (7.6 m)

4 MECHANICAL AND ELECTRICAL SYSTEMS FOR SMALL BUILDINGS

This chapter will help you select a heating and cooling system for the preliminary design of a small building. It also summarizes typical plumbing and electrical systems for small buildings.

DESIGNING MECHANICAL AND ELECTRICAL SERVICES FOR SMALL BUILDINGS

Small buildings are defined for purposes of this section as those that use residential-scale mechanical and electrical systems. This category may include small educational, commercial, retail, industrial, and institutional buildings as well as houses, townhouses, and small apartment buildings.

Heating and cooling loads in small buildings are usually dominated by heat gains and losses through the enclosure of the building. Historically, in many such buildings, mechanical fresh air ventilation has not been a major concern because of the low density of occupancy and the ability of operable windows and normal air leakage through the building skin to provide air exchange between the interior and exterior. However, with modern high-performance construction techniques that more effectively limit incidental air leakage through the building enclosure, attention to indoor air quality and properly designed fresh air ventilation has taken on greater importance.

Most of the distribution lines for the mechanical and electrical systems in small buildings can be concealed within the hollow cavities that are a normal part of the floor, wall, and ceiling structures of small buildings. A basement, crawlspace, or attic is often available as well, serving as a location for major mechanical equipment and larger horizontal distribution lines.

There is an enormous variety of heating and cooling systems from which the designer may choose. This section summarizes the choices of systems as well as describes typical plumbing and electrical systems. Approximate dimensions of the components of the various systems are given.

THE ENVIRONMENTAL IMPACTS OF HEATING AND COOLING SMALL BUILDINGS

In North America, the heating and cooling of buildings is a major contributor to the region's total energy consumption. For this reason, designing heating and cooling systems that use less energy, or that rely on more environmentally sustainable forms of energy, is an important consideration for any building. As you review the following pages, be sure to give consideration to systems and strategies that can contribute to reducing the environmental impact of you building. For example:

- Give preference to heating and cooling systems that operate most efficiently.
- Consider systems that reduce reliance on nonrenewable fossil fuels—coal, petroleum, and natural gas—which, when consumed, are major contributors to climate change.
- Integrate energy-saving strategies such as energy recovery (page 175), energy storage (page 190), geothermal exchange (page 183), and passive systems (pages 221–238) into heating and cooling designs where possible.
- Design to high-performance building standards such as green building certifications, net zero energy, passive house, or others.

For more information about building heating and cooling systems and the environment, see page 163.

DESIGN CRITERIA FOR THE SELECTION OF HEATING AND COOLING SYSTEMS FOR SMALL BUILDINGS

Decide first if the building needs a heating system, cooling system, or both heating and cooling:	Some systems are capable of heating only, such as: Hydronic heating (pages 250–251) Active solar heating (page 252) Electric baseboard convectors (page 255) Electric fan-forced unit heaters (page 256) Radiant panel heating (page 257) Wall furnace and direct-vent space heaters (page 258) Heating stoves (page 259) Passive solar heating (pages 228–230) Some systems are capable of both heating and cooling the building, such as: Forced air (pages 247–249) Heat pump furnace (pages 248–249) Small packaged heating and cooling units (page 254) Single-packaged and split-packaged systems (pages 192–194) Some systems are capable of cooling only, such as: Packaged evaporative cooler (page 253) Natural ventilation cooling (pages 231–233) Thermal mass cooling (pages 234–236) Passive evaporative cooling (pages 237–238)
If you wish to minimize the first cost of the system:	Choose systems that do not require the installation of extensive piping or ductwork, such as: Packaged evaporative cooler (page 253) Small packaged heating and cooling units (page 254) Ductless split-packaged systems (page 193) Electric baseboard convectors (page 255) Electric fan-forced unit heaters (page 256) Wall furnace and direct-vent space heaters (page 258) Heating stoves (page 259) or consider a passive heating or cooling system, such as: Passive solar heating (pages 228–230) Natural ventilation cooling (pages 231–233) Thermal mass cooling (pages 234–236) Passive evaporative cooling (pages 237–238)
If you wish to minimize operating costs and energy consumption in cold climates:	Choose fossil-fueled fire systems with attention to energy-saving variations, such as: Forced air heating with heat or energy recovery ventilator (page 249) Hydronic heating with radiant heated floors (page 251) or choose systems that rely on renewable energy sources, such as: Active solar heating (page 252) Passive solar heating (pages 228–230) or choose systems that burn locally available, low-cost fuels, such as: Heating stoves (page 259)

DESIGN CRITERIA FOR THE SELECTION OF HEATING AND COOLING SYSTEMS FOR SMALL BUILDINGS

If you wish to minimize operating costs and energy consumption in moderate climates:	Choose systems that extract heat or energy from ambient sources, such as: Heat pump systems (pages 184, 248–249) Active solar heating (page 252) Packaged evaporative cooler (page 253) or choose systems that burn locally available, low-cost fuels, such as: Heating stoves (page 259) or consider a passive system: Passive solar heating (pages 228–230) Natural ventilation cooling (pages 231–233) Thermal mass cooling (pages 234–236) Passive evaporative cooling (pages 237–238)
If you wish to maximize control of air quality and air velocity for maximum comfort:	Choose a system that filters and moves the air mechanically, namely: Forced air (pages 247–249)
If you wish to maximize individual control over temperature:	Choose systems that offer separate thermostats in a number of rooms or zones, such as: Hydronic heating (pages 250–251) Small packaged heating and cooling units (page 254) Split-packaged systems (pages 192–194) Electric baseboard convectors (page 255) Electric fan-forced unit heaters (page 256)
If you wish to minimize the noise created by the heating and cooling system:	Choose systems in which motors, pumps, and fans are distant from the occupied space, such as: Forced air (pages 247–249) Hydronic heating (pages 250–251) Active solar heating (page 252) Packaged evaporative cooler (page 253) Electric baseboard convectors (page 255) Radiant heating (page 257) or consider a passive system: Passive solar heating (pages 228–230) Natural ventilation cooling (pages 231–233) Thermal mass cooling (pages 234–236) Passive evaporative cooling (pages 237–238)
If you wish to minimize the visual obtrusiveness of the heating and cooling system:	Choose systems that place as little hardware as possible in the occupied spaces, such as: Forced air (pages 247–249) Packaged evaporative cooler (page 253) Hydronic radiant heating (page 251) Passive solar heating (pages 228–230) Natural ventilation cooling (pages 231–233) Thermal mass cooling (pages 234–236) Passive evaporative cooling (pages 237–238)

DESIGN CRITERIA FOR THE SELECTION OF HEATING AND COOLING SYSTEMS FOR SMALL BUILDINGS

If you wish to maximize the inhabitants' enjoyment of the changing weather and seasons:	Choose systems that change prominently with the seasons, such as: Heating stoves (page 259) Passive solar heating (pages 228–230) Natural ventilation cooling (pages 231–233) Thermal mass cooling (pages 234–236) Passive evaporative cooling (pages 237–238)
If you wish to minimize the amount of building area occupied by heating and cooling equipment:	Choose systems that do not occupy floor space, such as: Packaged evaporative cooler (page 253) Small packaged heating and cooling units (page 254) Split-packaged systems (pages 192–194) Electric baseboard convectors (page 255) Electric fan-forced heaters (page 256) Electric radiant heating (page 257) Wall furnace and direct-vent space heaters (page 258) Passive solar heating (pages 228–230) Natural ventilation cooling (pages 231–233) Thermal mass cooling (pages 234–236) Passive evaporative cooling (pages 237–238)
If you wish to minimize system maintenance:	Choose systems with few or no moving parts, such as: Forced air (pages 247–249) Hydronic heating (pages 250–251) Electric baseboard convectors (page 255) Electric radiant heating (page 257) Passive solar heating (pages 228–230) Natural ventilation cooling (pages 231–233) Thermal mass cooling (pages 234–236) Passive evaporative cooling (pages 237–238)
If you wish to avoid having a chimney in the building:	Choose systems that do not burn fuel in the building, such as: Heat pump furnace (pages 248–249) Active solar heating (page 252) Small packaged heating and cooling units (page 254) Single-packaged and split-packaged heat pump systems (pages 192–194) All types of electric heat (pages 254–257) Wall furnace and direct-vent space heaters (page 258) Passive solar heating (pages 228–230) With some fuel-burning systems, high-efficiency furnaces may be available that can be ventilated through a wall and do not require a chimney. Consult manufacturers' literature for more information.
If you wish to maximize the speed of construction:	Choose systems that involve as few components and as few trades as possible, such as: Small packaged heating and cooling units (page 254) Ductless split-packaged systems (page 193) All types of electric heat (pages 254–257)

HEATING AND COOLING SYSTEMS FOR SMALL BUILDINGS: SUMMARY CHART

GIVE SPECIAL CONSIDERATION TO THE SYSTEMS INDICATE IF YOU WITH TO:	**Forced Air (page 247)**	**Heat Pump Furnace (page 248)**	**Hydronic Heating (page 250)**	**Active Solar Heating (page 252)**	**Packaged Evaporative Cooler (page 253)**	**Small Packaged Units (page 254)**
Provide only heating or cooling, or both	Heating and cooling	Heating and cooling	Heating only	Heating only	Cooling only	Heating and cooling
Minimize first cost					•	•
Minimize operating costs and energy consumption in cold climates	•		•	•		
Minimize operating costs and energy consumption in moderate climates		•		•	•	
Maximize control of air velocity and air quality	•	•				
Maximize individual control over temperature			•			•
Minimize system noise	•	•	•	•	•	
Minimize visual obtrusiveness	•	•			•	
Maximize enjoyment of the seasons						
Minimize building area used for the mechanical system					•	•
Minimize system maintenance	•		•			
Avoid having a chimney		•		•		•
Maximize the speed of construction						•

HEATING AND COOLING SYSTEMS FOR SMALL BUILDINGS: SUMMARY CHART

					PASSIVE SYSTEMS			
Electric Baseboard Convectors (page 255)	**Electric Fan-Forced Unit Heaters (page 256)**	**Electric Radiant Heating (page 257)**	**Wall Furnace and Direct-Vent Space Heaters (page 258)**	**Heating Stoves (page 259)**	**Passive Solar Heating (page 228)**	**Natural Ventilation Cooling (page 231)**	**Thermal Mas Cooling (page 234)**	**Evaporative Cooling (page 237)**
Heating only	Heating only	Heating only	Heating only	Heating only	Heating only	Cooling only	Cooling only	Cooling only
•	•		•	•	•	•	•	•
				•	•			
				•	•	•	•	•
•	•							
•		•			•	•	•	•
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•	•	•	•		•	•	•	•
•		•			•	•	•	•
•	•	•	•		•			
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CENTRAL SYSTEMS VERSUS LOCAL SYSTEMS

In a *central system*, heat is supplied to a building or extracted from it by equipment situated in a mechanical space—a furnace or a boiler in a basement, for example. Air or water is heated or cooled in this space and distributed to the inhabited areas of the building by ductwork or piping to maintain comfortable temperatures. In a *local system*, independent, self-contained pieces of heating and cooling equipment are situated throughout the building, one or more in each room. Central systems are generally quieter and more energy-efficient than local systems, and offer better control of indoor air quality. Central equipment tends to last longer than local equipment and is easier to service. Local systems occupy less space in a building than central systems because they do not require a central mechanical space, ductwork, or piping. They are often more economical to buy and install. They can be advantageous in buildings that have many small spaces requiring individual temperature control.

Pages 247–252 describe central heating and cooling systems for small buildings, and pages 253–259 describe local systems.

FUELS

Heating equipment in small buildings may be fueled by oil, natural gas, liquid propane gas, kerosene, coal, electricity, sunlight, or wood. Cooling equipment is almost always powered by electricity. Passive systems rely on energy from natural systems, such as solar heat, air driven by the wind or convective pressures, and the evaporation of water.

Oil, natural gas, and liquid propane gas are widely available and efficient sources of energy. However, they are nonrenewable fossil fuels whose extraction entails environmental degradation and whose consumption is a major contributor to global climate change. Kerosene and coal are also fossil fuels, though with more limited regional availability. In comparison to other fossil fuels, coal has higher carbon emissions when burned, making it potentially a larger contributor to climate change.

Electricity, on the building site, is clean, is distributed through small wires, requires no chimney, and powers equipment that is more compact and often lower in first cost than equivalent fossil-fuel-burning equipment. However, its generation off-site often relies on the burning of fossil fuels. Electricity is not an efficient heat source when converted directly into heat, but it is many times more energy efficient when used to power air conditioners or heat pumps.

Wood is a less convenient energy source than gas, oil, or electricity, but can be suitable in buildings where owner preferences and building occupancy patterns permit or encourage its use.

For more information about mechanical system fuels and their environmental impacts, see page 240.

On-site storage requirements for the various fuels are summarized in the table below.

TYPICAL DIMENSIONS OF FUEL STORAGE COMPONENTS

Component	Width	Depth	Height
Coal storage, minimum, 1 ton (1 tonne)	4′-0″ (1.2 m)	4′-0″ (1.2 m)	4′-0″ (1.2 m)
Firewood storage, minimum, ½ cord	4′-0″ (1.2 m)	4′-0″ (1.2 m)	4′-0″ (1.2 m)
Liquid propane tanks, upright cylinders	16″ (410-mm) diameter		60″ (1525 mm)
Liquid propane tanks, horizontal	41″ (1040-mm) diameter, 16′-3″ (5.0 m) long		
There are many sizes of propane tanks, of which these are two of the most common. Upright cylinders are located outdoors, usually against the wall of the building, often in pairs. They may not be closer than 36″ (915 mm) to a door or a basement window. The horizontal tank must be at least 25′ (7.6 m) from the building or a property line and may be buried if desired.			
Oil or kerosene storage tank, 275 gal (1000 l)	27″ (685 mm)	60″ (1525 mm)	54″ (1375 mm)

For greater capacity, multiple tanks may be installed inside the building, or a larger tank may be buried just outside the foundation.

FORCED AIR HEATING AND COOLING

Description

A furnace heats air with a gas flame, an oil flame, or electric resistance coils. The heated air is circulated through the inhabited space by a fan and a system of ductwork. With an *upflow furnace*, the horizontal ducts are located above the furnace at the ceiling of the floor on which the furnace is located. With a *downflow furnace*, the ducts are located beneath the furnace in the crawlspace or floor slab. A third type, the *horizontal furnace*, is designed to fit in a low attic or underfloor crawlspace.

Cooling capability may be added to the furnace by installing evaporator coils in the main supply ductwork adjacent to the furnace. An outdoor compressor and condensing unit supplies cold refrigerant to the evaporator coils through small-diameter insulated tubing.

Typical Applications

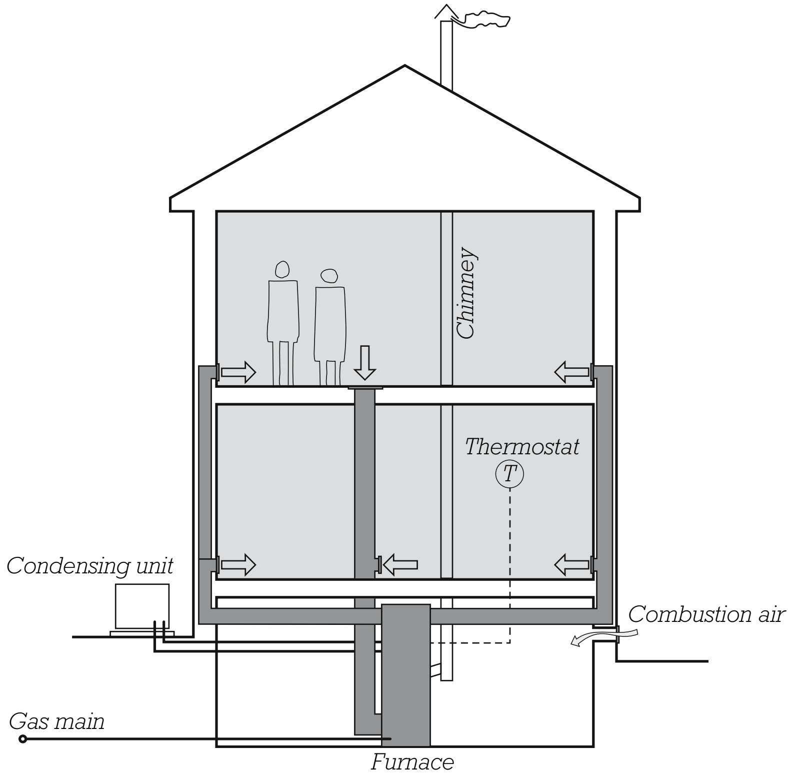
Forced air heating and air conditioning is the most versatile and most widely used system for heating and cooling small buildings. Multiple furnaces may be installed to establish zones of control and to heat and cool buildings of up to 10,000 sq ft (1000 m²) or more in area.

Advantages

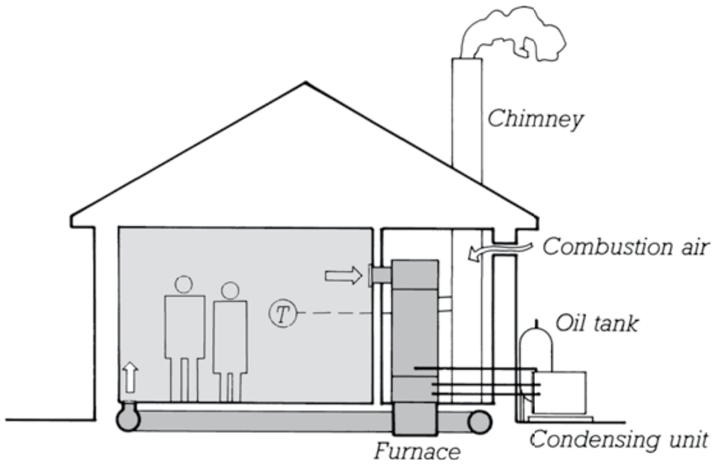
A forced air system can incorporate every type of humidification, dehumidification, air filtration, and cooling equipment. If properly designed, installed, and maintained, it is quiet and fuel efficient and distributes heat evenly.

Disadvantages

Multiple zones of control are relatively difficult to create.



UPFLOW FURNACE



DOWNFLOW FURNACE ON SLAB

Major Components

The major components of a forced air system are as follows: furnace, a source of fuel (utility-supplied or stored on site), chimney, ductwork, a source of outdoor air for combustion, and a thermostat for temperature control. If cooling capability is included, an outdoor condensing unit is required. If a high-efficiency gas furnace is used, a small-diameter pipe that can be vented through the roof or an exterior wall is used in place of a chimney, and access to a floor drain is needed for disposal of condensate from the furnace's combustion processes. Where outside air is required for interior ventilation, a duct running from the exterior may be used to introduce fresh air into the return air stream of the air-handling system.

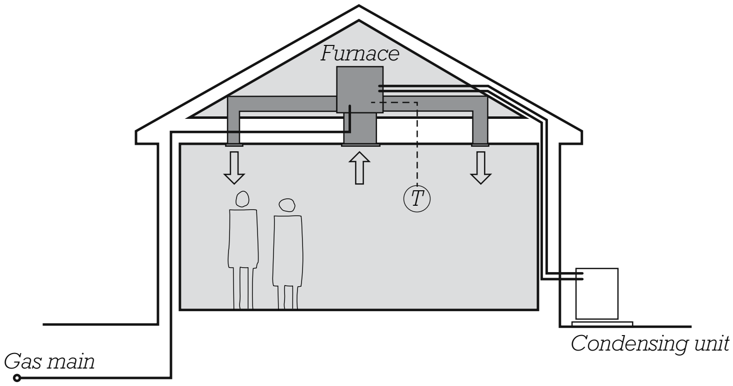
The simplest way to provide combustion air is to locate the furnace in an unconditioned mechanical space that is, itself, ventilated to the outdoors. In this case, the furnace can draw air directly from the surrounding space. However, locating the air-handling parts of the heating and cooling system outside of the building's thermal enclosure reduces system efficiency. If, instead, the mechanical space is partly or fully conditioned and not ventilated to the exterior, then a supply of fresh air must be brought close to the furnace through a duct from the exterior. Or, if a high-efficiency furnace is used, a small-diameter fully sealed air intake pipe supplies outside air directly to the furnace combustion chamber.

Typical dimensions for these components are summarized in the table on the facing page. For the dimensions of fuel storage components, see page 246.

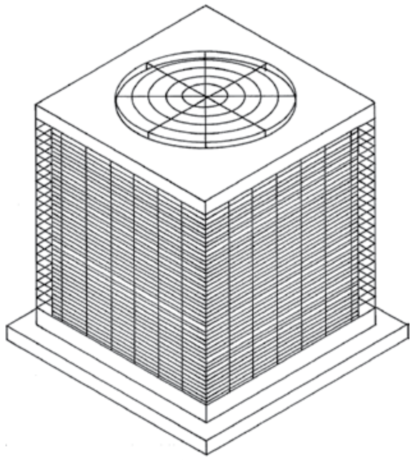
Variations

1. A *heat pump furnace* provides both heating and cooling with a reversible refrigeration cycle that either extracts heat from the outdoor air and releases it through coils within the furnace into the interior supply airstream or extracts heat from the coils in the furnace and releases it to the outdoor air, depending on whether heating or cooling is required. No burning of fuels or reliance on electric resistance coils is needed.

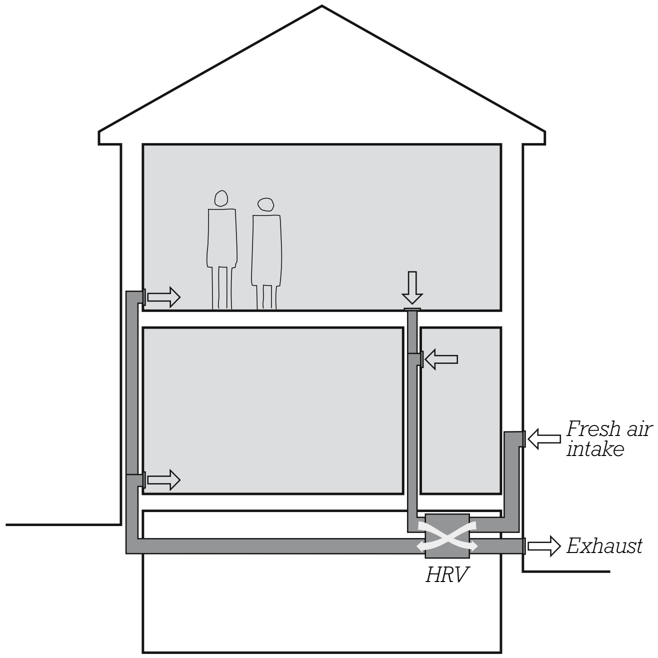
Heat pump furnaces are economical to operate in moderate climates, but quickly lose efficiency as outdoor temperatures fall much below freezing. For this reason, they



HORIZONTAL HEAT PUMP FURNACE IN ATTIC



EXTERIOR CONDENSING UNIT



FULLY DUCTED HEAT RECOVERY VENTILATOR

are not commonly used in colder climates. Heat pump furnace configurations and sizes are similar to those of fuel-burning furnaces.

2. A *heat recovery ventilator* (*HRV*) or *energy recovery ventilator* (*ERV*) captures heat energy that would otherwise be exhausted to the exterior and returns it to the interior, thereby increasing efficiency and reducing energy consumption. HRVs recover only sensible heat. They are best suited to cold climates and buildings with high interior relative humidity. ERVs recover both heat and humidity and are best suited to dry conditions where interior humidification is beneficial.

Fully ducted HRVs and ERVs operate with their own network of ducts independent from that of the heating and cooling system. Fully ducted systems operate most efficiently, provide consistently balanced air flow, and can supply fresh air reliably throughout the building interior. However, the added set of ducts adds cost and takes up additional space. Other configurations reduce ductwork requirements by integrating the HRV or ERV more closely into the return air stream of the forced air system.

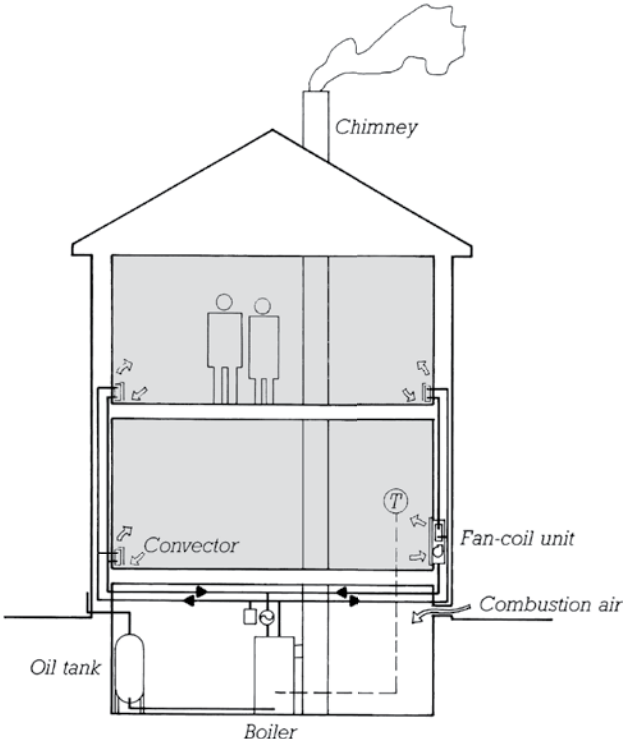
2. A *multifuel furnace* is designed to burn solid fuel (wood or coal) as well as a backup fuel (gas or oil). It is larger and more expensive than a single-fuel furnace.

3. A *packaged system*, either single-packaged or split-packaged, is often used to heat and cool small commercial, industrial, and institutional buildings. For information on packaged systems, see pages 192–194.

TYPICAL DIMENSIONS OF COMPONENTS OF FORCED AIR HEATING SYSTEMS

Component	Width	Depth	Height
Chimney, masonry	20″ (510 mm)	20″ (510 mm)	[a]
Chimney, metal	10″ (255-mm) diameter		[a]
Condensing unit, outdoor			
Small	24″ (610 mm)	24″ (610 mm)	24″ (610 mm)
Large	40″ (1015 mm)	50″ (1270 mm)	33″ (840 mm)
Ducts, sheet metal			
Main horizontal supply and return ducts, each	24″ (610 mm)		12″ (305 mm)
Supply risers, typical (notice that these are made to fit between wall studs)	10″ (255 mm) 12″ (305 mm) 7″ oval (175 mm oval)	3.25″ (83 mm) 3.25″ (83 mm)	
Return risers (these are usually fewer in number than the supply risers and require special wall framing provisions)	8″ (200 mm)	14″ (360 mm)	
For duct insulation, add 1″ (25 mm) all around. Insulation is recommended on heating ducts and is mandatory on cooling ducts that run through non-air-conditioned space.			
Fuel storage—see page 246			
Furnaces, including adjacent primary ductwork			
Horizontal furnace	24″ (610 mm)	84″ (1170 mm)	28″ (710 mm)
Upright furnace, upflow or downflow	24″ (610 mm)	30″ (760 mm)	84″ (1170 mm)
Multifuel furnace, upright, upflow	48″ (1220 mm)	60″ (1525 mm)	84″ (1170 mm)
Vent pipe (combustion exhaust), for high-efficiency gas furnace	1½-3″ (38–76-mm) diameter PVC, depending on furnace capacity and pipe length		
A working space 3′ (900 mm) square is required on the side of the furnace adjacent to the burner. Furnaces have varying requirements for installation clearances to combustible materials; some need only an inch or two.			

[a]Under most codes, a chimney must extend at least 3′ (900 mm) above the highest point where it passes through the roof and at least 2′ (600 mm) above any roof surface within a horizontal distance of 10′ (3 m).



Description

A flame or electric resistance coil heats water in a boiler. Small pumps circulate the hot water through fin-tube convectors, which are horizontal pipes with closely spaced vertical fins mounted in a simple metal enclosure with inlet louvers below and outlet louvers above. The heated fins, working by convection, draw cool room air into the enclosure from below, heat it, and discharge it out the top. Instead of fin-tube convectors, especially where space is tight, fan-coil units, either surface-mounted or wall-recessed, may be used. The fan in a fan-coil unit blows room air past a hot water coil to heat it.

Typical Applications

Hydronic heating is a premium-quality heating system for any type of building. Radiant systems (described on the facing page) create especially comfortable thermal environments for building occupants.

Advantages

Hydronic heating is quiet if properly installed and maintained. It gives excellent heat distribution and is easily zoned for room-by-room control by adding thermostatically controlled zone valves or zone pumps at the boiler. The boilers for small-building systems are very compact. Some gas or electric boilers are so small that they can be mounted on a wall.

Disadvantages

Cooling, fresh air supply, air filtration, and humidification, if desired, must be accomplished with independent systems, which raise the overall system cost. The convectors occupy considerable wall perimeter and can interfere with furniture placement.

Major Components

The major components of a hydronic heating system are as follows: boiler, chimney, fuel storage or supply, expansion tank, circulator pumps, zone valves, convector or fan-coil units. Some high-efficiency gas boilers may be vented through a wall and do not require a chimney.

Typical dimensions for these components are summarized in the table to the right. For dimensions of fuel storage components, see page 246.

Variations

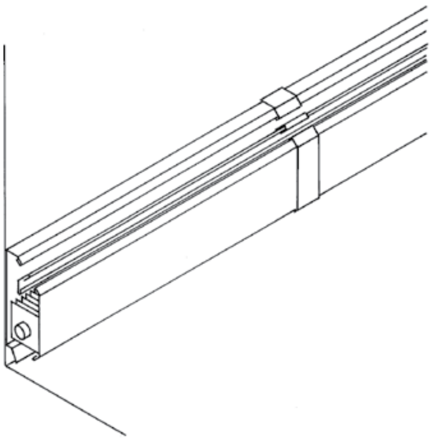
1. A *multifuel boiler* is designed to burn both solid fuel (coal or wood) and a backup fuel (gas or oil). It is larger and more expensive than a single-fuel boiler.

2. *Radiant heated floors or ceilings* are warmed with hot water from a hydronic boiler circulated through ceiling panels or floor assemblies. Because these systems rely on relatively large exposed surface areas to radiate heat, rather than just warm the air, they can create a more comfortable thermal environment for the building occupants. For more information about hydronic radiant heated floors and ceilings, see page 183. For information about electric radiant floors and ceilings, see page 257.

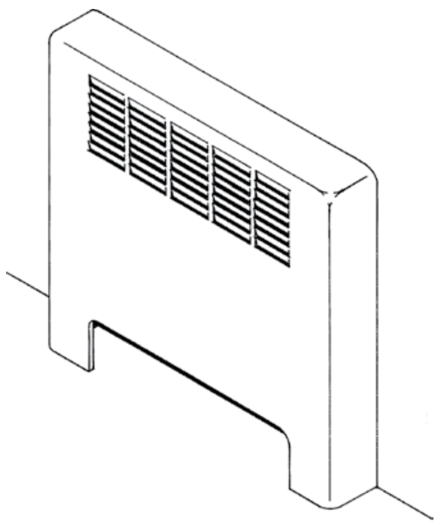
TYPICAL DIMENSIONS OF COMPONENTS OF A HYDRONIC HEATING SYSTEM

Component	Width	Depth	Height
Chimney, masonry	20″ (510 mm)	20″ (510 mm)	[a]
Chimney, metal	10″ (250-mm) diameter		[a]
Boiler, hydronic, with expansion tank, valves, and pumps (add 10″ or 250 mm on two adjacent sides for piping)			
Upright	25″ (635 mm)	25″ (635 mm)	84″ (2135 mm)
Wall-mounted, gas or electric	30″ (760 mm)	24″ (610 mm)	84″ (2135 mm)
Solid fuel or combustion fuel	36″ (900 mm)	60″ (1530 mm)	84″ (2135 mm)
A boiler requires a working space 3′ (910 mm) square on the side adjacent to the burner. Required clearances to combustible surfaces vary, depending on the design of the boiler; for some boilers, they may be as little as an inch or two.			
Convector, baseboard	3″ (75 mm)	7.5″ (190 mm)	
Fan-coil units			
Recessed or surface mounted	24″ (610 mm)	4″ (100 mm)	30″ (760 mm)
Toe kick heater	21″ (535 mm)	18″ (460 mm)	4″ (100 mm)

[a]Under most codes, a chimney must extend at least 3′ (900 mm) above the highest point where it passes through the roof and at least 2′ (600 mm) above any roof surface within a horizontal distance of 10′ (3 m).



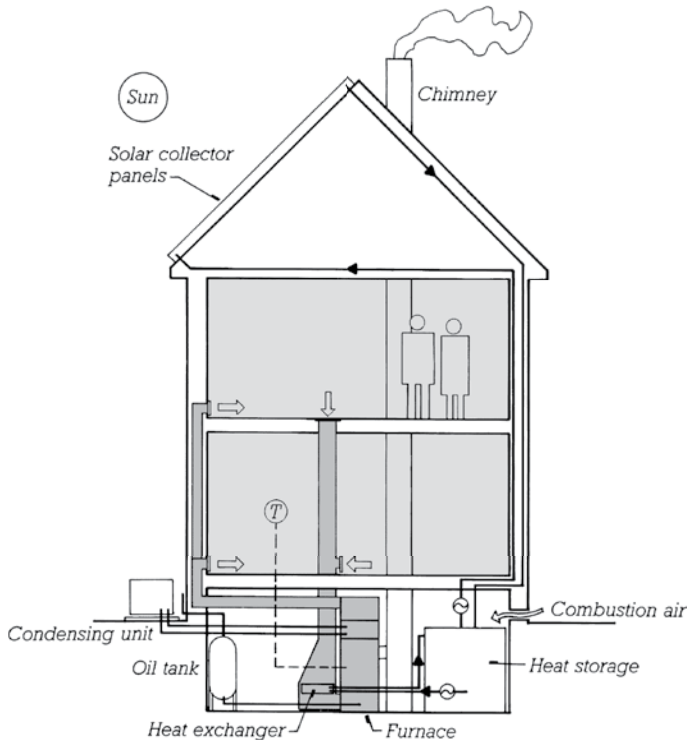
HYDRONIC CONVECTOR



FAN-COIL UNIT

Description

Outdoor south-facing collector panels, usually mounted on the roof of the building, are heated by sunlight. A pump or fan circulates liquid or air to withdraw heat from the panels and store it in a tank of liquid or a bin of rocks or phase-change salts. This storage is usually located in the basement or a mechanical equipment room. A fan circulates indoor air through a heat exchanger coil filled with the warm storage liquid, or through the rock bin, and distributes the heated air to the inhabited space of the building through a system of ductwork.



Typical Applications

Active solar heating is feasible in buildings that are exposed to sunlight throughout the day in climates with a high percentage of sunny weather during the winter.

Advantages

No fuel is required. Only relatively small quantities of electricity are required to power pumps or fans.

Disadvantages

The initial cost of active solar heating systems tends to be high. The collector surfaces may become a prominent part of the architecture of the building. A backup heating system (such as forced air or hydronic heating) is usually required to heat the building during extended sunless periods. Cooling must be done by a separate system.

Major Components

The major components of an active solar heating system area as follows: solar collector panels, heat storage tank or bin, ductwork for air collectors or piping for water collectors, fans or pumps, heat exchanger, and building heating ductwork. Typical dimensions for these components are summarized in the table to the right. For the dimensions of fuel storage components, see page 246.

Variations

A heat pump may be added to the system to draw heat from the storage medium at relatively low temperatures and distribute it to the occupied spaces at higher temperatures. This provides a higher degree of comfort and increases the efficiency of the solar collectors.

Solar collector panels may be used to provide heat to the building domestic water system, either in addition to, or in lieu of, providing space heating.

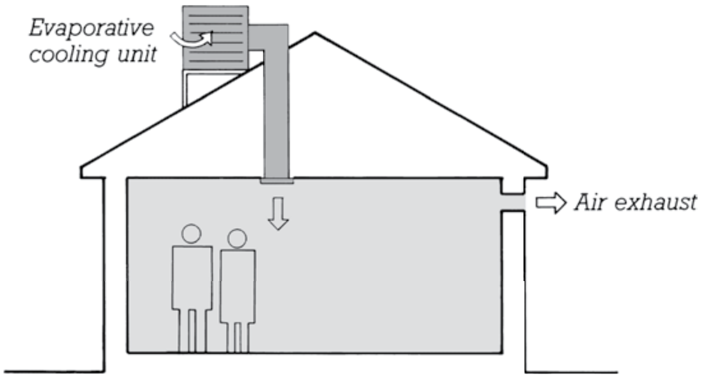
TYPICAL DIMENSIONS OF ACTIVE SOLAR HEATING COMPONENTS

Component	Width	Depth	Height
For dimensions of the backup furnace, chimney, fuel storage, and ductwork, see pages 246 and 249.			
Collector panels, average residence	24′ (7.3 m)	6″ (150 mm)	20′ (6 m)
Collector panels should face within 20° of true south and should be sloped at an angle to the ground equal to or up to 15° more than the latitude of the site.			
Heat exchanger with ductwork	30″ (760 mm)	30″ (760 mm)	30″ (760 mm)
Heat storage			
Rock bed	Minimum of 600 ft^3 (17 m^3)		
Water storage tank	8′ (2.4 m) diameter		7′ (2.1 m)

PACKAGED EVAPORATIVE COOLER

Description

A fan blows warm, dry outside air through a wetted pad. Water evaporates from the pad into the air, cooling the air by extracting from it the latent heat of vaporization. The fan circulates the cooled, humidified air through the building. The metal cabinet in which the pad and fan are placed is usually located on the roof or adjacent to the building.



Typical Applications

Evaporative coolers are used to cool buildings in which humidity control is not critical, in hot, dry climates.

Advantages

Cooling costs are significantly lower than those of refrigeration-cycle systems. No environmentally hazardous refrigerants are used in the equipment.

Disadvantages

Evaporative coolers are only suitable for dry climates where added humidity does not decrease occupant comfort. The system is ineffective in humid climates. A separate system is required for heating the building.

Major Components

The major components of this system are the evaporative cooling unit and ductwork. Typical dimensions for these components are summarized in the accompanying table.

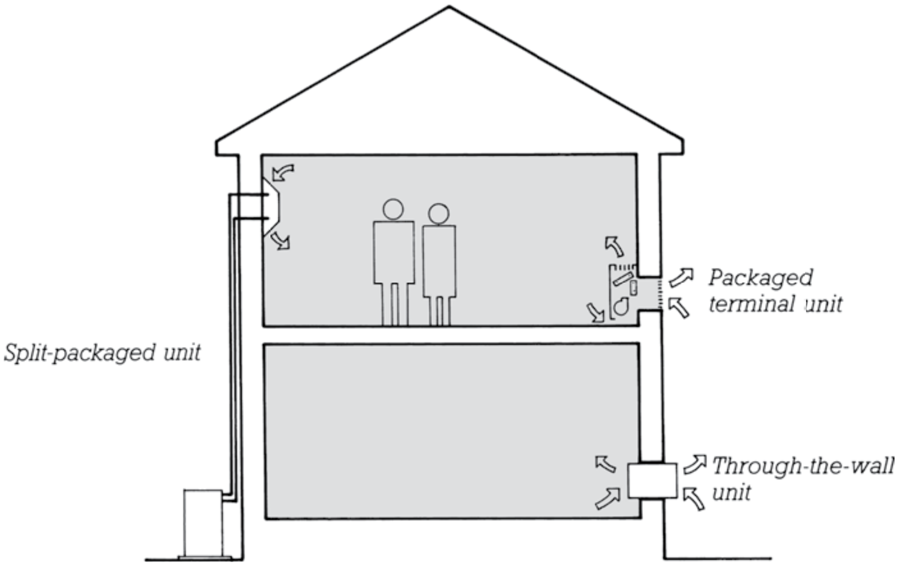
TYPICAL DIMENSIONS OF EVAPORATIVE COOLING SYSTEM COMPONENTS

Component	Width	Depth	Height
Evaporative cooler, average	36–48″ (915–1220 mm)	36–48″ (915–1220 mm)	24–36″ (610–915 mm)
Duct	18″ (460 mm)	18″ (460 mm)	

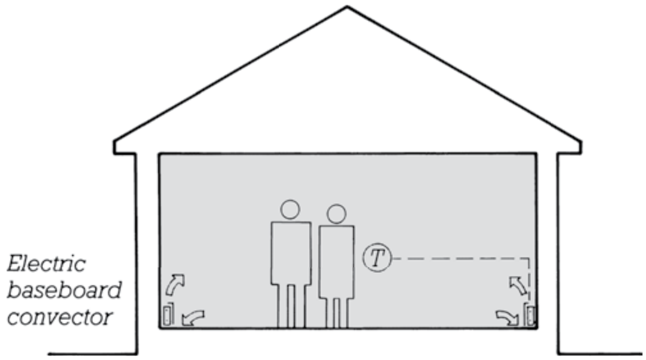
SMALL PACKAGED HEATING AND COOLING UNITS

Small, local packaged terminal units, through-the-wall units, and mini-split-units are used extensively in small buildings. These systems are described more fully on page 184.

For larger buildings or where central zonal control is needed, central packaged systems can also be used. See pages 192–194 for more information.



ELECTRIC BASEBOARD CONVECTORS



Description

Electric resistance wires in sheet metal enclosures are installed around the perimeter of the room at the junction of the floor and the wall. Room air circulates through slots in the enclosures by means of convection and is heated by the resistance wires.

Typical Applications

Heating systems in buildings of any type, especially where electricity costs are low.

Advantages

Electric baseboard convectors are quiet and distribute heat evenly. Each room has individual temperature control. Installation costs are low. No chimney is required.

Disadvantages

The baseboard convectors occupy considerable wall perimeter and can interfere with furniture placement. There is no means of controlling humidity or air quality. Electricity is an inefficient source of heat, and in most areas it is expensive in comparison to other fuels. A separate system is required for cooling.

Major Components

The major components of this system are the electric baseboard convector units. A typical convector is 3 in. (75 mm) deep and 7.5 in. (190 mm) high and extends for some feet along a wall.

ELECTRIC FAN-FORCED UNIT HEATERS

Description

Fan-forced electric unit heaters are compact units inside which a fan draws in room air and heats it, by passing it over electric resistance wires, before blowing it back into the room.

Typical Applications

Any room or building that requires electric heating from small sources.

Advantages

Fan-forced unit heaters are economical to buy and install, and they do not interfere with furniture placement as much as baseboard convectors. Each room has individual temperature control. No chimney is required.

Disadvantages

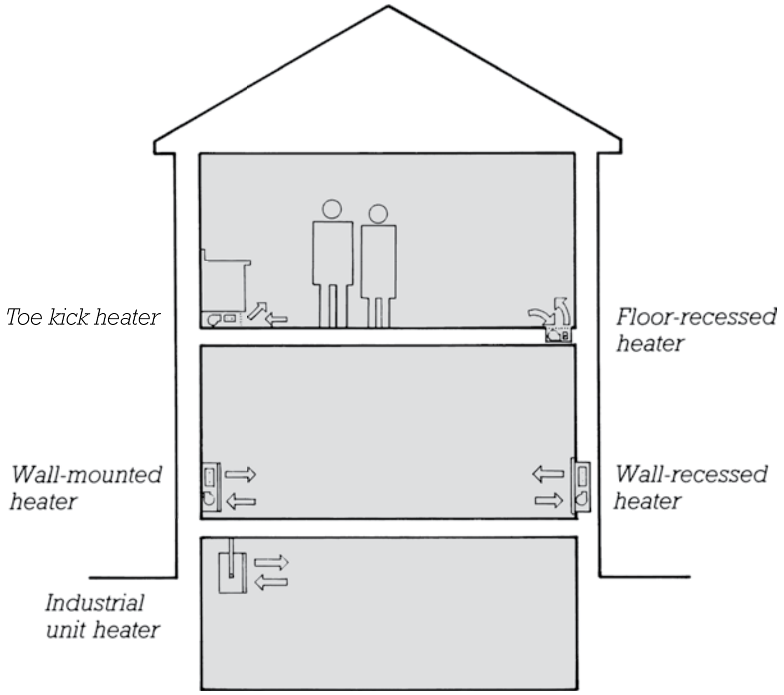
Heat distribution in the room can be uneven, and the fans become noisy unless they are maintained regularly. There is no means of controlling humidity or air quality. Electricity is an inefficient source of heat, and in most areas it is expensive in comparison to other fuels. Separate systems are required for humidification and cooling.

Major Components

The major components of this system are the electric fan-forced unit heaters. Typical dimensions for these components are summarized in the table to the right.

Variations

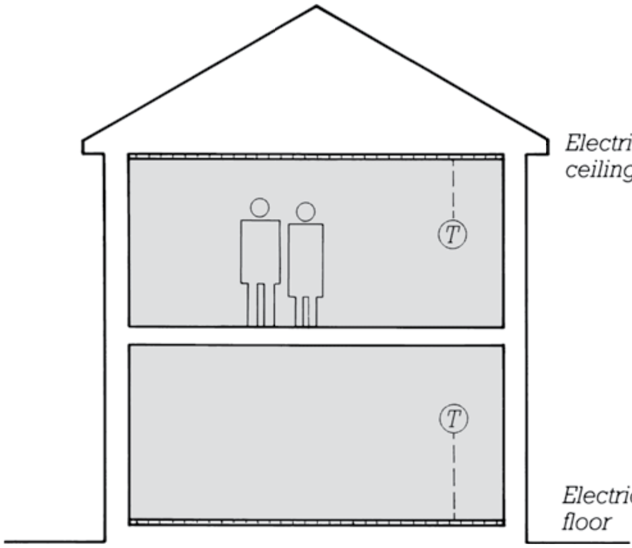
Fan-forced unit heaters are available for wall mounting in recessed or surface-mounted configurations. *Toe kick heaters* are designed for use in the low, restricted space under kitchen cabinets, bathroom vanities, or shelving. Recessed floor units lie beneath a simple floor register. Industrial unit heaters are mounted in rectangular metal cabinets that are designed to be suspended from the roof or ceiling structure.



TYPICAL DIMENSIONS OF ELECTRIC FAN-FORCED HEATERS

Component	Width	Depth	Height
Floor-recessed heater	16″ (400 mm)	8″ (200 mm)	8″ (200 mm)
Industrial unit heater	16″ (400 mm)	12″ (300 mm)	16″ (400 mm)
Toe kick heater	24″ (610 mm)	12″ (300 mm)	4″ (100 mm)
Wall-recessed or wall surface-mounted heater	16″ (400 mm)	4″ (100 mm)	20″ (510 mm)

ELECTRIC RADIANT HEATING



Description

Electric resistance heating wires are embedded in the ceiling or floor. The warm surface radiates heat directly to the body and also warms the air in the room.

Typical Applications

Residences, nursing homes.

Advantages

Heating is even and comfortable. No heating equipment is visible in the room.

Disadvantages

The system is slow to react to changing needs for heat. Tables and desktops beneath a radiant ceiling cast cold "shadows" on the legs and feet. Carpeting and furniture reduce the effectiveness of radiant floor panels. Cooling and humidity control must be provided by a separate system. Electricity is an inefficient source of heat, and in most areas it is expensive in comparison to other fuels.

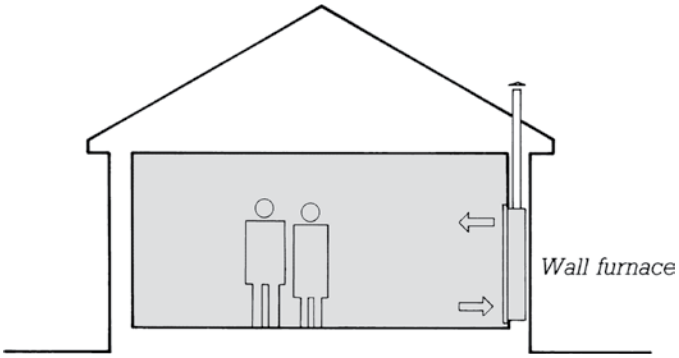
Major Components

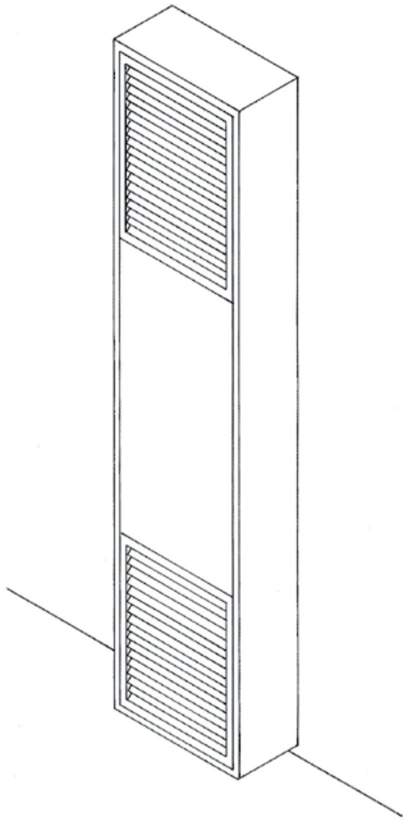
The major components of electric radiant heating systems are resistance wires, resistance mats, or prefabricated, electrified ceiling panels.

Variations

Ceiling or floor radiant panels may be heated by hot water coils fed from a hydronic boiler.

WALL FURNACE AND DIRECT-VENT SPACE HEATERS





WALL FURNACE

Description

A *wall furnace* is a tall wall-recessed or surface-mounted heating unit in which air flows from the room and circulates by convection past metal heat exchange surfaces warmed by a gas flame. Most wall furnaces can heat the spaces on both sides of the wall. Sometimes a short run of ductwork can be added to circulate heat to a third room.

Direct-vent space heaters are a newer generation of self-contained heating units. Inside air is fan-forced over a sealed burner unit. The unit draws exterior air for combustion and may be fueled by kerosene, natural gas, or propane. In comparison to wall furnaces, direct-vent space heaters are smaller in size, have greater fuel efficiency, provide improved heat distribution, and offer more choices of fuel source. These units are usually surface-mounted on the inside of an exterior wall, or vent pipes may be extended 10 to 15 ft (3 to 4.5 m) horizontally or vertically to permit more choice in heater location.

Typical Applications

Low-cost dwellings, offices, and motels in mild climates.

Advantages

Both systems are inexpensive to buy and install. Direct-vent space heaters are highly fuel efficient.

Disadvantages

Both systems require vent pipes to the outdoors, distribute heat unevenly, and are unattractive visually. Cooling and humidity control must be provided by separate systems.

Major Components

For wall furnaces, the major components are a gas meter and service entrance or a propane tank and regulator, gas piping, wall furnace, and vent pipes through the wall or to the roof. A typical wall furnace is 14 in. wide, 12 in. deep, and 84 in. high (360 × 305 × 2135 mm). The vent pipe to the roof is typically a 4-in. (100-mm) oval that may be concealed between the studs in a wall.

For direct-vent space heaters, the fuel supply may consist of a gas service entrance and meter, propane tank and regulator, or kerosene tank. Kerosene may be gravity-fed, or, if the heater is above the level of the tank, a lift pump may be used. Heater unit dimensions are 16–38 in. wide, 9–16 in. deep, and 21–28 in. high (405–965 × 230–450 × 535–710 mm). Dual concentric vent pipes that provide both fresh air intake and combustion exhaust may be extended through the exterior wall or roof, and range in size from 2 to 3 in. (50 to 75 mm) in outside diameter.

HEATING STOVES

Description

Heating stoves are small appliances that sit conspicuously within each area they heat. They burn wood, coal, gas, oil, or kerosene and transmit heat to the room and its occupants by a combination of convection and radiation.

Typical Applications

Used in residential, industrial, and commercial buildings, especially in areas where firewood or coal is inexpensive and readily available. Wood- and coal-burning stoves are frequently used as supplementary sources of heat in centrally heated houses.

Advantages

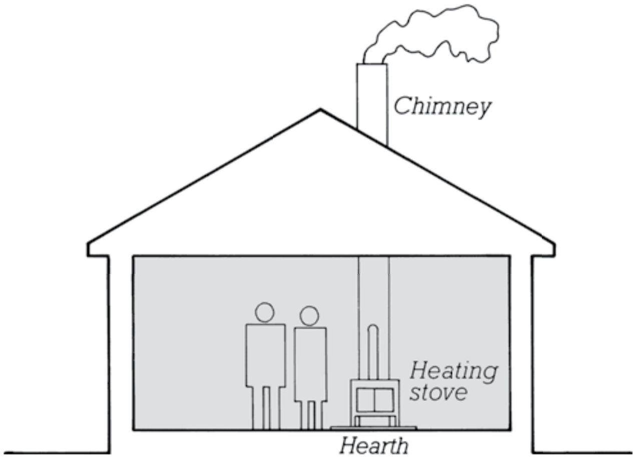
Wood and coal are cheap fuels in many areas, and the experience of tending a stove and basking in its warmth can be aesthetically satisfying. Some stoves are visually attractive.

Disadvantages

Heating stoves use a surprisingly large amount of floor space and require chimneys. Most stoves are hot enough to burn the skin. They do not distribute heat evenly. Solid-fuel stoves require constant tending and are difficult to control precisely. Solid fuel and ashes may generate considerable dirt within the building. A stove becomes a fire hazard unless it and its chimney are conscientiously maintained and operated. Most solid-fuel stoves pollute the air due to incomplete combustion.

Major Components

Major components of heating stove systems are as follows: chimney, stove and stovepipe, floor protection, wall protection, fuel storage, and ash storage for solid-fuel stoves. Typical dimensions for these components are summarized in the table to the right.



TYPICAL DIMENSIONS OF HEATING STOVES

Component	Width	Depth	Height
Ash storage	Covered metal bucket 14″ (360 mm) in diameter		
Chimney, masonry			
One stove	20″ (510 mm)	20″ (510 mm)	[a]
Two stoves	20″ (510 mm)	28″ (710 mm)	[a]
Chimney, metal	10″ (254-mm) diameter		
Fuel storage: see page 246			
Stove			
Gas-fired	38″ (965 mm)	13″ (330 mm)	40″ (1015 mm)
Oil-fired	32″ (815 mm)	30″ (760 mm)	40″ (1015 mm)
Wood-fired	Varies widely up to the dimensions shown for gas-fired and oil-fired stoves		
Stovepipe, uninsulated, typical	7″ (180- mm) diameter		
Stovepipe, insulated, typical	9″ (230- mm) diameter		

Heating stoves typically require a clearance of 36″ (914 mm) to combustible or plaster surfaces. They also require a noncombustible hearth that extends 12″ (305 mm) to each side and to the back of the stove, and 18″ (460 mm) to the front. Some stoves are shielded to allow them to be as close as 12″ to combustible surfaces to the back and sides. An uninsulated metal stovepipe may not come closer than 18″ (460 mm) to the ceiling. Insulated pipes are usually designed for a 2″ (51-mm) clearance to combustible materials.

[a]Under most codes, a chimney must extend at least 3′ (900 mm) above the highest point where it passes through the roof and at least 2′ (600 mm) above any roof surface within a horizontal distance of 10′ (3 m).

WATER SUPPLY

Water from a municipal main reaches the building via an underground service pipe and a water meter. In warm climates, the meter may be outside the building, but in cold climates, it must be installed in a heated space, usually the basement or the mechanical equipment room. In many areas an electronic readout, connected by wires to the inside water meter, is mounted on the outside of the building so that the meter reader does not need to enter the building. Meters can also be read remotely with various wireless technologies.

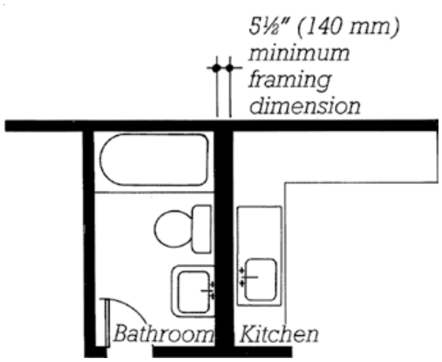
From the water meter, domestic cold water flows directly to the fixtures by means of small-diameter copper or plastic pipes. If the water is “hard” (contains a heavy concentration of calcium ions), a water softener may be installed to remove these ions from the water that goes to the domestic water heater. The water heater uses a gas flame, an oil flame, solar-heated liquid, electric heat pump, or electric resistance heating to warm the water to a preset temperature at which it is held in an insulated tank for subsequent use. A tree of hot water piping parallels the cold water piping as it branches to the various fixtures in the building. Supply piping should be kept out of exterior walls of buildings in cold climates, to prevent damage to piping from wintertime freeze-ups.

If water is obtained from a private well, it is lifted from the well and pressurized by a pump. If the well is deep, the pump is placed at the well bottom. If the well is less than approximately 20 to 25 ft (6 to 8 m) deep, the pump may be located inside the building. In either case, the pump pushes the water into a pressure tank, from which it flows on demand into the hot and cold water piping. The pressure tank may be located inside the well, or in the basement or mechanical equipment room of the building.

WASTE PIPING AND SEWAGE DISPOSAL

Sewage flows from each fixture through a trap into waste pipes that drain by gravity. To ensure that the traps do not siphon dry, and to maintain constant atmospheric pressure in the waste piping, a vent pipe is attached to the waste system near each trap. The vent pipes rise through the building until they penetrate the roof, where they are left open to the air. The vent pipes may be gathered together into a single pipe in the attic of the building to minimize the number of roof penetrations. A horizontal run of vent can be used to move a plumbing vent to a less prominent rooftop location.

The waste piping descends through the building, gathering



waste from all the fixtures, until it reaches the ground, the crawlspace, or the basement. If it lies above the sewer or the private disposal system at this point, it turns to an almost horizontal orientation, sloping toward its outlet (the sewer main or the septic tank) at a pitch of at least 1:100. If it lies below the elevation of its outlet at this point, an automatically operated underground ejector pump must be installed to lift the sewage and empty it into the outlet.

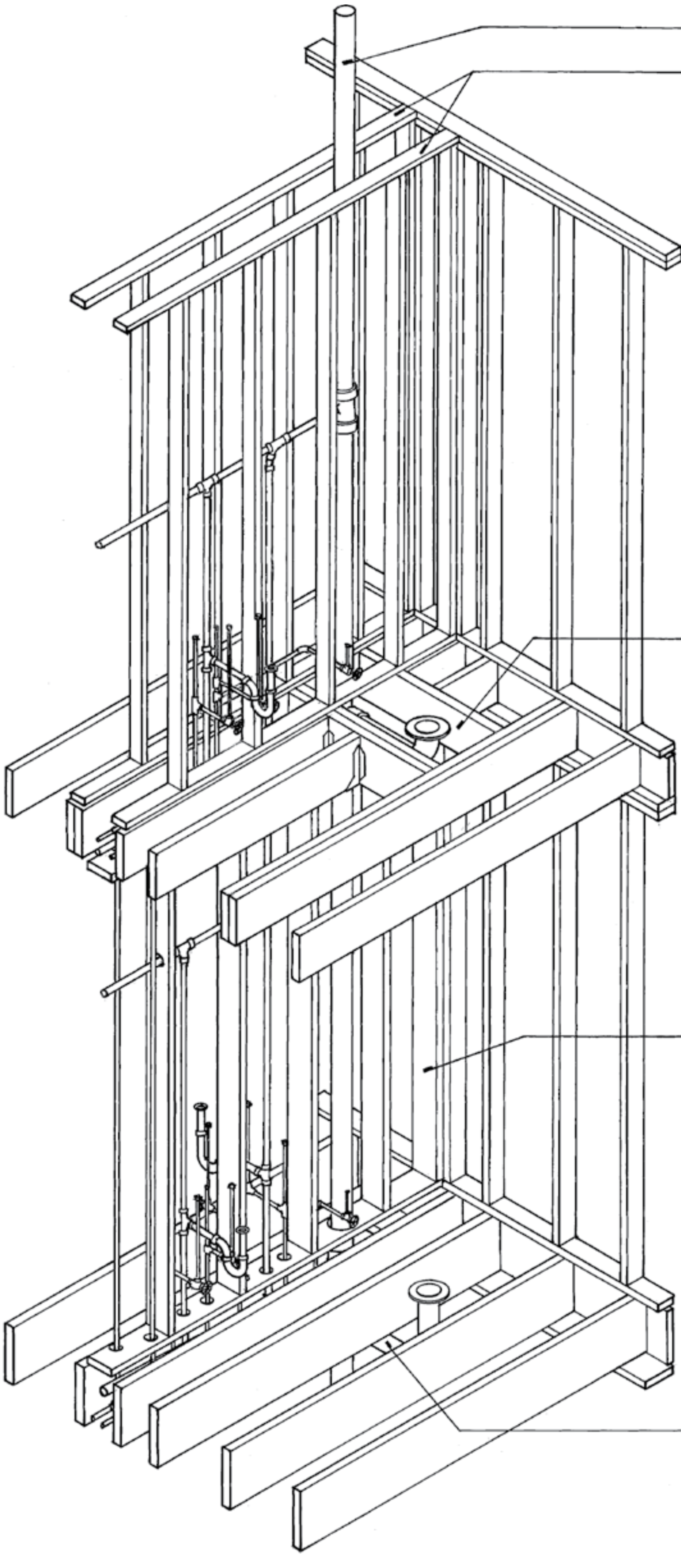
TYPICAL DIMENSIONS OF PLUMBING COMPONENTS

Component	Width	Depth	Height
Gas meter and piping	18″ (460 mm)	12″ (305 mm)	24″ (610 mm)
Sewage disposal, private			
The size and configuration of private sewage disposal systems vary widely, depending on soil conditions, topography, local laws, and the required capacity of the system. As a starting point, allow an area of level or nearly level ground 40′ × 80′ (12 × 25 m), with its short side against the building. No part of this area may be closer than 100′ (30 m) to a well, pond, lake, stream, or river.			
Water heater			
Gas-fired	20″ (510-mm) diameter		60″ (1525 mm)
Electric	24″ (610-mm) diameter		53″ (1350 mm)
Water meter and piping	20″ (510 mm)	24″ (305 mm)	10″ (255 mm)
Water pressure tank for a pump that is located in a well	20″ (510-mm) diameter		64″ (1625 mm)
Water pump and pressure tank for a shallow well	36″ (915 mm)	20″ (510 mm)	64″ (1625 mm)
Water softener	18″ (460-mm) diameter		42″ (1070 mm)

Waste and vent piping is larger in diameter than supply piping and requires careful planning to fit efficiently into a building. Stacking bathrooms and toilet rooms avoids expensive and space-consuming horizontal displacements of the waste and vent stacks. For maximum economy, fixtures should be aligned along thickened plumbing walls, and rooms containing fixtures should be clustered back-to-back around the plumbing walls. The major horizontal runs of waste piping should be located in a crawlspace, beneath a slab, or just inside the perimeter of a basement. Some typical wood framing details for plumbing walls are shown in the diagram to the right.

Private sewage disposal systems vary considerably in configuration and size, depending chiefly on soil conditions and local health regulations. The most common type includes a septic tank, usually 1000 to 1500 gal (4000 to 6000 l) in capacity, in which the sewage is digested by anaerobic action. Effluent from the septic tank flows by gravity to a disposal field of perforated pipe laid below ground in a bed of crushed stone. In nearly all areas of North America, private sewage disposal systems may be designed only by a qualified engineer. The engineer's design is based on soil tests that in some municipalities may be performed only during those limited periods of the year when the soil is in its most saturated condition, and a building permit will not be issued until a permit has been granted for the construction of the disposal system. This can potentially delay the start of a construction project for many months.

Typical dimensions of plumbing components are summarized in the table on the facing page.



FRAMING DETAILS FOR PLUMBING WALLS

GAS SERVICE

Natural gas is distributed to buildings through utility mains located beneath the street. Each building is served by an underground pipe that surfaces at a gas meter and pressure regulator next to or just inside the building. From this service entrance, the gas is piped through the building to the various appliances— furnaces, boilers, water heaters, clothes dryers, fireplaces, barbecues, kitchen ranges, and industrial equipment.

Where there are no gas mains, liquid propane gas can be delivered by tanker truck to pressurized tanks outside the building. The gas flows from the tanks through a pressure regulator and evaporator into the building's gas piping system.

Gas piping is small in diameter and is made up of threaded iron pipe and fittings. It does not usually require special consideration in the design of the building, but space does need to be provided, usually at the basement ceiling or in the crawlspace or slab, for long horizontal runs of gas piping.

For dimensions of gas meters in a small building, see the table on page 260. For dimensions of liquid propane storage tanks, see the table on page 246.

SPRINKLER SYSTEMS IN SMALL BUILDINGS

Small building sprinkler system requirements vary with the Occupancy and size of the building. To determine whether sprinklers are required for your project, consult the height and area tables on pages 394–449 for buildings regulated by the International Building Code, and pages 450–479 for buildings regulated by the National Building Code of Canada.

Where the height and area tables indicate that sprinklers are required, and no further information is provided about sprinkler system type, a commercial-grade (NFPA 13) sprinkler system should be assumed, and the guidelines for large building sprinkler systems provided on pages 206 and 214 should be followed.

Where the height and area tables indicate that a lighter-duty, NFPA 13R (residential) sprinkler system is permitted, follow the same commercial-grade sprinkler system guidelines noted in the previous paragraph, with the following exceptions:

- Due to reduced water supply demands, no fire pump is normally required. Where water supply is inadequate, a gravity tank or air-pressurized tank may provide the necessary backup.
- A relatively small assembly of valves and alarm fittings joins the sprinkler system to the domestic water supply.
- An exterior Siamese fitting for hookup to fire department pumper trucks may be required.
- Dedicated sprinkler riser shafts may not be required. The smaller-diameter piping typical of this system may fit comfortably into available wall cavities.
- A maximum coverage of 144 sq ft (13 m^2) of floor area per sprinkler head should be assumed.
- Sprinkler coverage does not need to extend into attics, bathrooms, and small bathrooms or closets.

Where the height and area tables indicate that an NFPA 13D (one- and two-family dwelling) sprinkler system is permitted, use the following guidelines:

- This system is connected directly to the building's domestic water supply system. No fire pump is required.
- Assume a maximum coverage of 144 sq ft (13 m^2) of floor area per sprinkler head.
- Sprinkler coverage must extend throughout living areas but need not include attics, crawlspaces, small closets, small pantries, small bathrooms, garages, carports, exterior porches, and unheated entry areas.
- Sprinkler piping for this system is small in diameter, takes up little space, and is easy to install. It may be metallic or of several kinds of plastic. Nonmetallic piping must be separated from interior spaces by a layer of gypsum wallboard or other material that offers at least short-term protection from the heat of fire.

ELECTRICAL AND COMMUNICATIONS WIRING FOR SMALL BUILDINGS

Electrical, telephone, data, and cable television services reach the building via either overhead or underground wires, depending on the practices of the local utilities. Overhead wires at the street may be converted to an underground service to the building by running the service wires down the face of the pole to the required depth and then laterally to the building. Data may also be provided by optic fiber.

An electric power meter is mounted in an accessible location on the outside of the building. Wires from an overhead service arrive at the building above the meter and descend to it in a large cable or a metal conduit mounted on the exterior wall surface. Wires from an underground service are brought up to the meter in a conduit. A cable or conduit from the meter enters the building at the basement or main-floor level and connects to the main electric panel, which should be as close to the meter as possible.

From the main panel, wiring fans out to branch panels and individual circuits. Exposed wiring or wiring in masonry or concrete must be placed in metal or plastic conduits. In frame buildings, most wiring is done with flexible plastic-sheathed cable that is routed through the cavities of the frame. In a very small building, all the branch circuits connect directly to the main panel. In a larger building, especially one with multiple tenant spaces, most circuits connect to branch panels scattered at convenient points around the building. The branch panels, in turn, are connected by cables or conduits to the main panel.

Panel locations need to be worked out fairly early in the building design process. In small framed buildings, the designer seldom needs to be concerned about providing space for the wires and cables unless the construction system features exposed framing members and decking. In this case, conduit routes for the wiring must be carefully planned to avoid visual chaos.

Wiring systems for data networks, telephone, cable television, centralized entertainment systems, security systems, smoke and fire alarms, intercoms, antennas, and so on generally have minimal impact on the planning of a small building in the early stages of design. At their simplest, such systems may not require any dedicated space, or may require only small, wall-mounted panels that can share space in general-purpose closets, basements, or mechanical equipment rooms. As systems increase in complexity, dedicated wiring closets may be necessary. Such closets should be centrally located to best accommodate the star topology of most such systems, and to minimize the length of individual cable runs. For example, a central stair may offer closet space at its lowest level, as well as easy cable access up through the center of the building; at each floor or ceiling level, cables can then branch out to reach their final destinations. Closets must be located so that cable lengths do not exceed their maximum limits for reliable performance. Most common types of ethernet local area network cabling are limited to 328 ft (100 m) in length. However, some categories of high-speed cable are limited to shorter lengths where maximum performance is required. To avoid electrical interference from other systems, communications closets should be separated from electrical service entrance cables, service panels, lightning protection, and mechanical equipment by at least 6 ft (1.8 m).

Typical dimensions of components of electrical systems in small buildings are summarized in the table below.

TYPICAL DIMENSIONS OF COMPONENTS OF ELECTRICAL SYSTEMS

Component	Width	Depth	Height
Electric meter	12″ (305 mm)	9″ (230 mm)	15″ (380 mm)
Main panel	14″ (360 mm)	4″ (100 mm)	27″ (685 mm)
Branch panel	14″ (360 mm)	4″ (100 mm)	20″ (685 mm)

SECTION

5

DESIGNING FOR EGRESS AND ACCESSIBILITY

1 CONFIGURING THE EGRESS SYSTEM AND PROVIDING ACCESSIBLE ROUTES

This chapter will assist you in the preliminary design of exits, corridors, stairways, other egress components, accessible spaces, and accessible routes, in accordance with the requirements of the model building codes.

COMPONENTS OF THE EGRESS SYSTEM

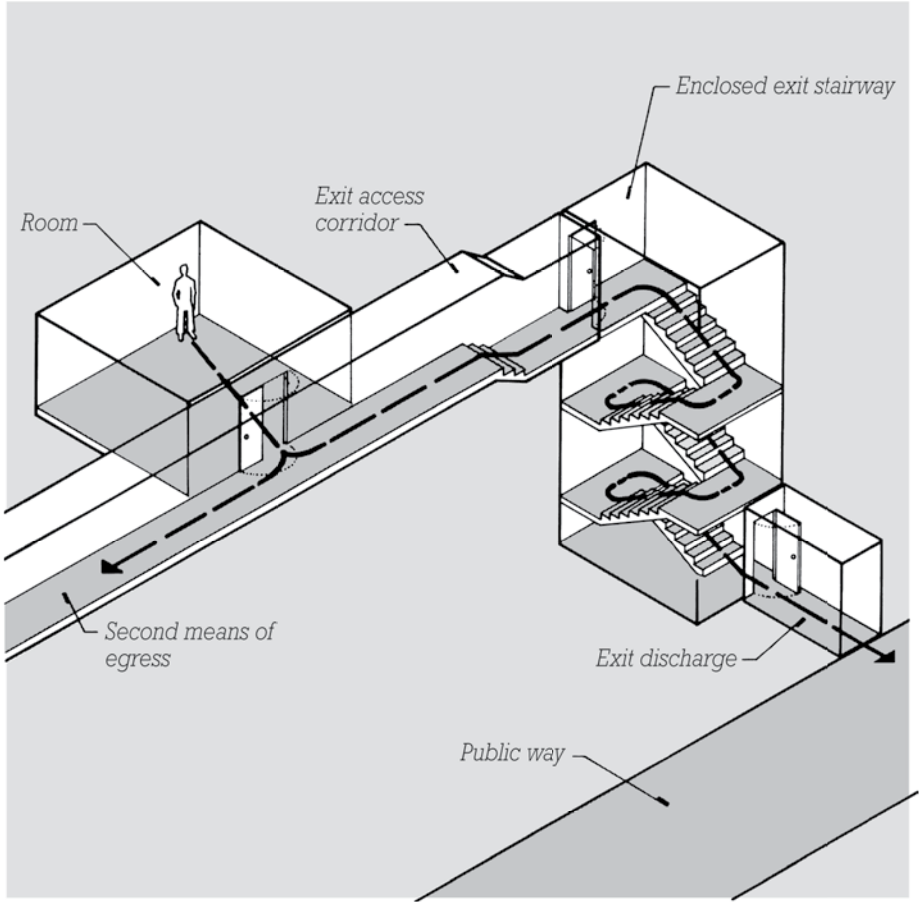
The function of a building egress system is to conduct building occupants to a safe place in case of a fire or other life-safety emergency. In most instances, that safe place is a public way or other large, open space outside the building. For the occupants of the upper floors of a tall building, or for people who are incapacitated or physically restrained, the safe place may also be a protected area of refuge within the building itself.

A building egress system has three parts:

1. The *exit access* begins at any point in the building. It may include pathways within a room, aisles between seating, hallways, corridors, ramps, unenclosed stairways, and other spaces. The exit access is unprotected, or only minimally protected, from smoke and fire. It ends when the building occupant reaches the exit.

2. The *exit* is the protected portion of the egress system. Most commonly, it is an enclosed, fire-protected stairway that leads from the upper floors of a building to a door at grade opening to the outside. It may also include enclosed, protected passageways, or protected areas of refuge within the building.

3. The *exit discharge* is the final portion of the egress system that connects the exit to the public way or other place of safety. In many cases, the exit discharge consists only of exterior elements, such as sidewalks, stairs, and so forth that lead from the building to the public sidewalk or street. The exit discharge may also include limited portions of the building interior, such as when the egress path leaves an exit stair and passes through a vestibule or ground floor lobby before reaching the exterior.



These three parts of an egress system are discussed in greater detail on the pages that follow. Also included are simplified standards for the preliminary design of these components, condensed from the model building codes treated in this book.

EXIT ACCESS PATHS

Every occupied space in or on a building must have access to a means of egress so that occupants can leave the building safely in an emergency. Where a room or space is small and serves only a limited number of occupants, only a single means of egress may be required. Larger spaces require two or more means of egress, each independent from the others. Multiple independent egress paths help to ensure that larger numbers of occupants can safely and efficiently exit from a space, and they provide alternate routes of escape if one pathway is rendered unsafe or unreachable.

Wherever more than one exit access pathway is required, the capacity of the individual pathways should be balanced so that the loss of any one will not reduce the remaining capacity to less than one-half of the total required. This means, for example, that where two egress paths are required, each one must be able to provide at least one-half of the total required egress capacity. Or, if three paths are required, any combination of two must be able to provide at least one-half of the required capacity.

International Building Code

The International Building Code limits spaces and mezzanines with single means of egress based on the Occupancy, number of occupants, presence of sprinklers, and length of the single-exit route. See the table on pages 306–307 for more information. Areas exceeding the limits for a single means of egress require at least two independent means of egress. Spaces with an occupant load exceeding 500 require three independent means of egress, and those with an occupant load exceeding 1000 require four.

National Building Code of Canada

In the National Building Code of Canada, any room, area, or occupied roof with an occupant load exceeding 60 generally requires two independent means of egress. Requirements for independent means of egress also vary with the size of the space, the type of Occupancy, and the presence or absence of sprinklers. See the table on pages 312–313 for more information.

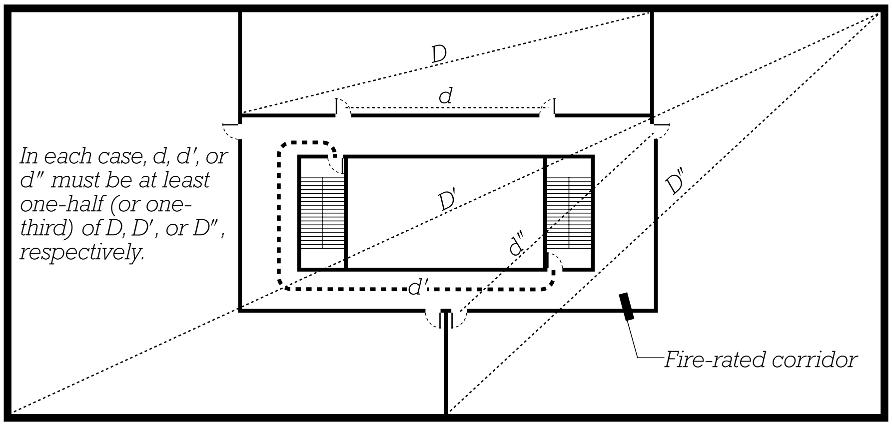
Individual dwelling units within Residential Occupancies are permitted to have just one means of egress when a single exit door leads directly to the exterior not more than 1.5 m (5 ft) above grade, and the exit door is within one story of every floor level within the unit, or the uppermost floor of the unit opens to an exterior balcony that is not more than 6 m (20 ft) above grade.

EGRESS THROUGH ADJACENT SPACES

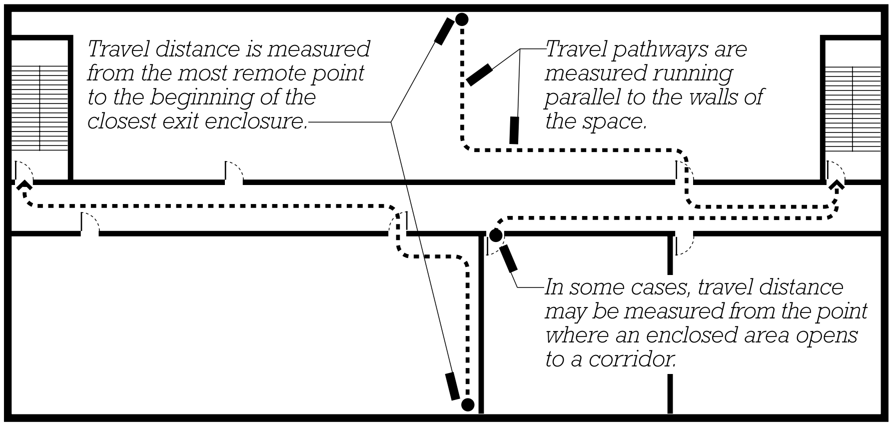
In their simplest configuration, exit access pathways proceed from rooms to shared corridors and then to enclosed exits.

The International Building Code permits exit access pathways to flow through intermediate functionally related spaces. However, once an exit access path reaches a corridor or hallway, it must proceed directly to an exit stair or other exit component and cannot reenter other spaces. In nonresidential occupancies, the exit access should not pass through kitchens, storage rooms, closets, or other spaces with a likelihood of becoming obstructed. From within dwelling units, exit access should not pass through bathrooms or sleeping areas other than one's own.

The National Building Code of Canada does not permit exit access pathways to pass through separate tenancies, separate dwelling units, building service or equipment rooms, or spaces of differing Occupancies.



INTERNATIONAL BUILDING CODE DISTANCE BETWEEN EXITS



TRAVEL DISTANCE

DISTANCE BETWEEN EXITS

Wherever more than one egress pathway is required from a room or area, these pathways must be sufficiently remote from one another to minimize the possibility that they will become simultaneously unsafe or inaccessible in a building emergency.

International Building Code

In the International Building Code, where a room, space, or whole floor requires more than one means of egress, at least two of these must be separated by a distance of not less than one-half the maximum diagonal measure of the area served. Or, where the building is fully sprinklered, the distance may be reduced to one-third the diagonal measure of the area. Normally, these distances are taken as straight-line measurements. However, when exits off a floor are interconnected by a 1-hour rated corridor, the distance between the two exits is measured along the path of travel in the corridor. See the diagram on this page. For special exit separation requirements for tall buildings, see page 297.

National Building Code of Canada

In the National Building Code of Canada, where two egress doorways are required from one space, the doorways must be separated by a distance of at least one-third the diagonal measure of the space served.

When considering exits off a floor, the required distance between exits is one-half the diagonal measure of the floor or 9 m (30 ft)—the lesser of the two measurements when the exits are accessed from a corridor, or the greater of the two when no corridor is provided. No minimum distance between exits is required where a floor is subdivided by fire separations into two or more major areas, each containing its own exit.

In this code, distance between doorways or exits is measured as a straight line when open areas are served. Where spaces are subdivided, the distance is measured as the shortest pathway that smoke can take to travel between the doorways or exits, such as along corridors or through other confined spaces.

MAXIMUM TRAVEL DISTANCE TO THE EXIT

Travel distance is measured along the exit access. It is the distance from the most remote point in a space to the beginning of the nearest exit (such as the start of an exit stair or other exit component of the egress system). Building codes limit travel distance so that in the event of an emergency, the amount of time that persons may be exposed to fire, smoke, toxic gases, or other unsafe conditions is limited. Maximum permitted travel distances vary considerably depending on the Occupancy, presence of sprinklers, and the particular code. See pages 306–307 and 312–313 for more information.

Travel distance must be measured along paths that an occupant realistically takes to reach the exit portion of the egress system. For example, where most rooms and spaces can be expected to be furnished with tables, desks, arrayed seating, or other fixtures that restrict directions of movement, travel distance should be measured along paths that reflect such conditions. Usually, travel distance is measured along paths running parallel to the walls of the space. Travel within enclosed exit components is not included in travel distance measurements. For example, in a multistory building, travel distance is measured from remote points on any floor to the nearest door leading to an enclosed exit stairway. Travel within the stairway is not included.

International Building Code

Travel along unenclosed stairways or ramps is included in travel distance measurements, and is measured parallel to the plane of the stair or ramp, not in horizontal plan projection.

National Building Code of Canada

Travel distance from rooms or suites separated from the remainder of the floor and opening onto a corridor or exterior passageway may be measured from the doorway of the space leading to the corridor or passageway, rather than from the most remote point within the room or suite. On an unsprinklered floor, the separation between the rooms or suites and the remainder of the floor must have at least a 45-minute fire-resistance rating. On sprinklered floors, no fire-resistance rating is required.

For rooms or suites in fully sprinklered buildings, served by a corridor at least 9 m (30 ft) wide and with a ceiling at least 4 m (13 ft) high, this code permits travel distance of up to 105 m (344 ft), provided that, where any space requires more than one means of egress, not more than half the required means of egress will utilize the corridor. This exception is primarily intended for commercial mall buildings.

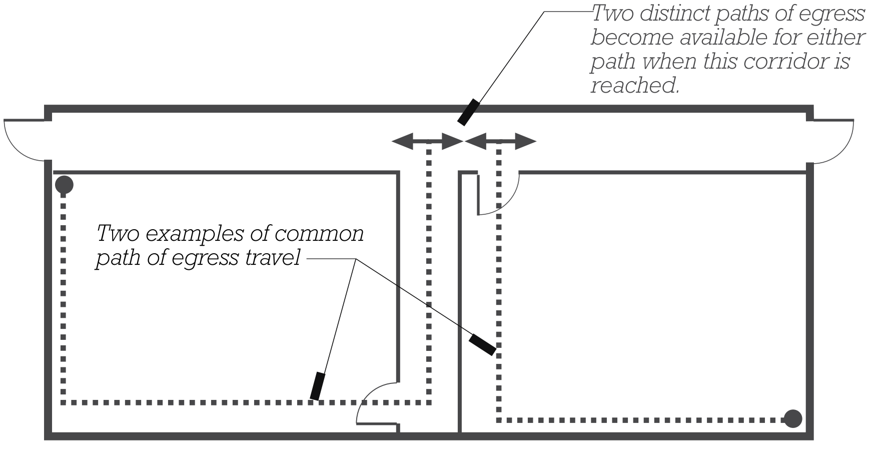
This code also permits large floor areas to forgo other stated travel distance limits when all main aisles in the space lead directly to exits arrayed around the perimeter at not greater than 60 m (197 ft) apart. This exception does not apply to F-1 High-Hazard Industrial Occupancies, and is mainly intended for large, ground-level Assembly Occupancy spaces where exits lead directly to the exterior.

TRAVEL LIMITATIONS WITHIN THE EXIT ACCESS

When a space is permitted only one means of egress, the maximum travel distance to a point at which two independent means of egress become available is also limited.

In the International Building Code, the distance an occupant must travel before two independent means of egress become available is called the *common path of egress travel*. For example, in a room with just one doorway leading to a corridor, where the corridor provides egress in two separate directions, the length of the common path of egress travel would be the travel distance within the room and through the doorway to the corridor. See the diagram on this page. In the International Building Code, common path of egress travel limits for most Occupancies range from 75 to 125 ft (23 to 38 m). See page 306 for more details.

In the National Building Code of Canada, where a room or space is permitted only one means of egress, the travel distance from any point in the space to its egress doorway cannot exceed 10 to 25 m (33 to 82 ft), depending on the Occupancy and the presence or absence of sprinklers. See the table on page 312 for more details. Upon leaving the room and entering a corridor or exterior passageway, the occupant must be provided with two independent paths of egress (except where whole-floor, single-exit conditions are permitted).



INTERNATIONAL BUILDING CODE COMMON PATH OF EGRESS TRAVEL

CORRIDORS

Corridors are dedicated exit access components that connect a floor's occupied spaces to its exits. Unlike other parts of the exit access, they are enclosed or separated from the spaces they serve. Corridors must be sufficiently wide to allow free passage of occupants, lead directly to exits, and be without lengthy dead ends in which occupants could inadvertently become trapped. Generally, they must not pass through intervening rooms. Depending on the type of Occupancy and number of occupants, corridor enclosures may be required to be fire-resistance rated, thereby providing a moderately raised level of protection as occupants move toward exits. When a related building use does occur within a corridor—for example, a reception area and desk—this use must not intrude into the required egress width of the exit access.

Corridor sizing information can be found on page 307 for the International Building Code and on page 313 for the National Building Code of Canada.

International Building Code

In the International Building Code, the level of fire resistance required for the walls and floor/ceilings enclosing a corridor varies with the Occupancy classification and the number of occupants, as listed in the following table. Where an occupant load is indicated, corridors with smaller occupant loads may have unrated enclosures. Foyers, lobbies, and reception areas may be included within corridors, if such spaces are separated from the remainder of the floor with enclosures meeting the same requirements as the corridor.

National Building Code of Canada

In the National Building Code of Canada, corridors must normally be enclosed with 45-minute fire-resistance rated walls and floor/ceiling assemblies. Corridors in some unsprinklered Assembly Occupancies must be enclosed with 1-hour rated assemblies. Corridors may be enclosed with unrated assemblies when the floor is fully sprinklered and any of the following conditions apply:

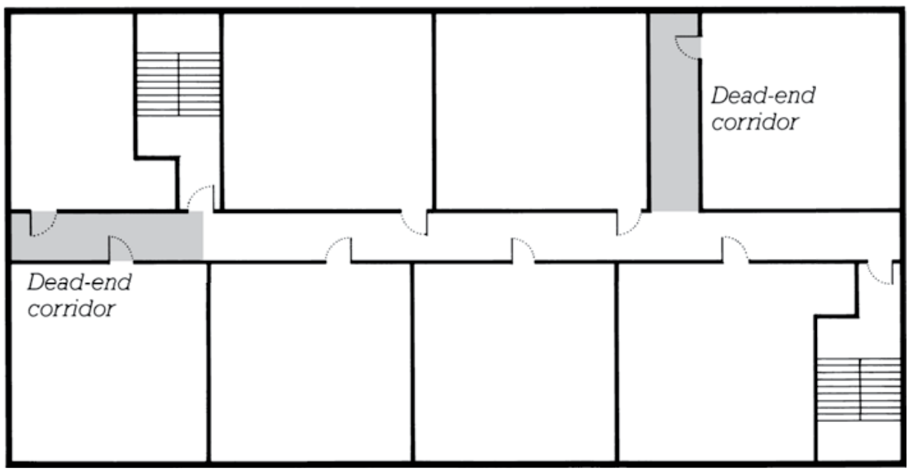
- The floor does not include any B Care, Treatment, Detention, or C Residential Occupancies.
- Travel distance from any point on the floor does not exceed 45 m (148 ft).
- Requirements for mall corridors are met; see the code for details.

Corridor Dead Ends

Wherever two means of egress are required, corridors may not include dead-end pockets exceeding 20–50 ft (6–15 m) in length, depending on Occupancy and other conditions. For more information, see page 307 for the International Building Code and page 313 for the National Building Code of Canada.

CORRIDOR PROTECTION IN THE INTERNATIONAL BUILDING CODE

Occupancy	Corridor Protection
A, B, E, F, M, S, U, with an occupant load greater than 30	Unrated if the building is sprinklered throughout; otherwise, 1-hour rated
B, corridors within areas requiring only a single exit	Unrated
E, where each instruction room and assembly room has at least one door leading directly to the exterior at grade	Unrated
All H-1, H-2, H-3	1-hour rated
H-4, H-5, with an occupant load greater than 30	1-hour rated
All I-1, I-3	1-hour rated
All I-2, I-4	Unrated
R, corridors serving an occupant load greater than 10	½-hour rated
I-1, R, corridors within dwelling or sleeping units	Unrated



DEAD END CORRIDORS

OPEN STAIRWAYS AND RAMPS

While exit stairways are normally enclosed, open stairways can also be part of the egress system.

International Building Code

In the International Building Code, open stairways are referred to as *exit access stairways*. In all Occupancies other than I-2 and I-3, they can be part of the egress system as follows:

- Stairs connecting mezzanines and other level changes within a single story
- Stairs that create an atmospheric connection between no more than two stories
- In R-1, R-2, and R-3 Occupancies, within individual dwelling or sleeping units, stairs connecting up to four stories
- Stairs within R-3 congregate residences and R-4 buildings
- In B and M Occupancies, stairs connecting an unlimited number of floors when the building is fully sprinklered, the floor opening is limited to twice the projected area of the stair, and draft curtains and other special sprinkler requirements are implemented
- In other than B and M Occupancies, stairs as in the previous bullet point, connecting up to four stories maximum
- Stairs within open-air seating
- Stairs connecting balconies, galleries, and press boxes to main assembly floors in theaters, places of worship, auditoriums, and sports facilities
- Stairs within atriums
- Stairs serving open parking garages

Whenever an open stairway forms part of the means of egress, an egress path can connect only two floors before reaching an exit component. In other words, even when an open stairway connects more than two floors, occupants' egress paths may only use this stairway to move from one floor to an adjacent floor before reaching an enclosed exit stair, exit passageway, horizontal exit, direct exit to the exterior, exterior exit stairway, or the like.

From the second floor of a building, all required means of egress may be provided with exit access stairways. On other floors, exit access stairways can provide up to one-half of the required number of means of egress, with the remaining ones being provided by enclosed exit stairways or other exit components directly accessible from that floor.

When a floor is permitted to have only a single means of egress, an open exit access stairway can be used, as long as travel distance limits to an exit on an adjacent floor are not exceeded (pages 271–272). This distance is measured from the most remote point on the floor to the beginning of the stairway, down the stairway, and continuing on until an enclosed exit component or door to the exterior of the building is reached on the floor below. Along the stairway, travel distance is measured parallel to the slope of the stair, not in plan projection. If this distance exceeds the maximum permitted by the code, the stairway must be enclosed, or some other change to the egress design must be made to provide a shorter path of travel to the nearest exit.

When a mezzanine is permitted to have only a single means of egress, an open exit access stairway may be used, as long as common path of egress travel limits are not exceeded. Common path of egress travel is explained on page 272. Open ramps serving as part of the means of egress are subject to the same requirements as open stairways.

National Building Code of Canada

Unenclosed egress stairways connecting two floors within a single tenant space are permitted in Small Buildings (see page 298), not more than two stories in height, containing only D Business and Personal Services or E Mercantile Occupancies. The tenant space must not occupy more than 100 m^2 (1076 sq ft) per story and must be separated from other spaces with 45-minute fire-resistance rated assemblies. From anywhere in the space, travel distance to an exterior exit must not exceed 25 m (169 ft). The floor assembly between the first floor and the basement must be 45-minute rated, and the floor between the first and second floors must have the same rating or be of noncombustible construction.

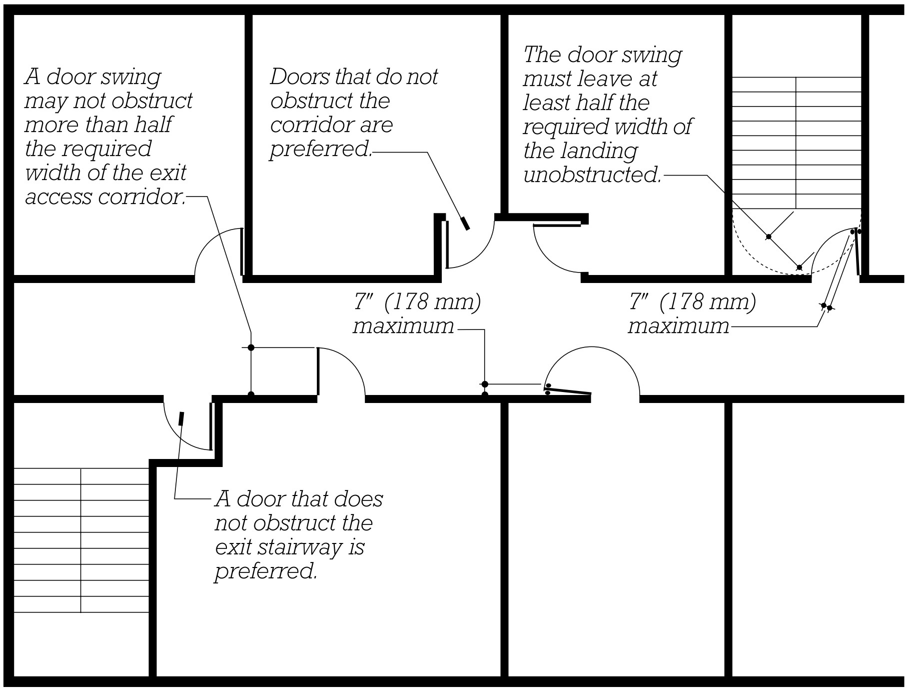
Unenclosed stairways are permitted for egress from some mezzanines, depending on mezzanine area and other factors. See page 378 for more information.

DOORS

In the International Building Code, most doors forming part of an egress path must operate by swinging or pivoting. Sliding doors or doors with other types of operation are permitted as egress doors within individual dwelling units, serving spaces with limited occupant loads, serving certain types of health-care suites, and in other unique circumstances. Doors serving an occupant load of 50 or more or any Group H Hazardous Occupancy must swing in the direction of egress travel.

In the National Building Code of Canada, egress doors opening into corridors, exits, and other exit access components (except within dwelling units) must be swinging doors. Sliding doors capable of breakaway swing action are also permitted. All exit doors, all egress doors within F-1 High-Hazard Occupancies, and any doors serving an occupant load greater than 60 must swing in the direction of egress travel.

Doorways must be arranged to minimize obstruction of egress pathways. The International Building Code limits door encroachment into required egress ways to not more than 7 in. (178 mm) when fully open, and not more than one-half of the required egress width throughout the door swing (except within individual dwelling units). In the National Building Code of Canada, fully open doors may encroach up to 100 mm (4 in.) into the required width of a corridor, or 50 mm (2 in.) of any other exit component. The door swing may not encroach into the required width of an exit corridor or passageway, but may reduce the required width of an



DOORS

exit stair or landing to not less than 750 mm (30 in.).

Even when locked, doors along an exit path must open easily in the direction of egress travel. Doors in fire-resistance rated walls must themselves be fire-resistance rated, although in some cases, to a value somewhat lower than the wall in which they are located.

Information on sizing of egress doorways may be found on page 307 for the International Building Code and on page 313 for the National Building Code of Canada.

REVOLVING DOORS

Revolving doors are permitted as egress components, provided that they are constructed to allow free passage in a panic situation by collapsing outward under pressure into a book-fold position.

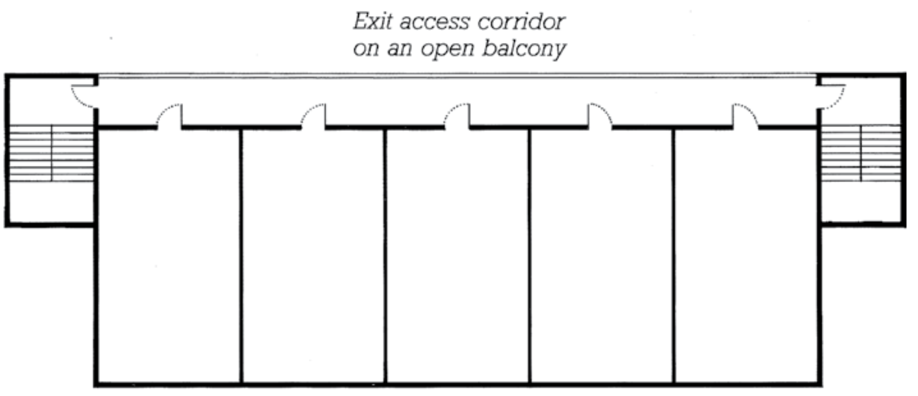
The International Building Code limits revolving doors to a capacity of 50 persons per door and, in total, to no more than half the required exit capacity of a building. There must be a swinging door in the same wall and within 10 ft (3 m) of the revolving door, and revolving doors may not be located within 10 ft (3 m) of the top or bottom of a stair or escalator.

The National Building Code of Canada limits the exit capacity of each revolving door to 45 persons and permits revolving doors to serve as egress for ground-floor occupants only. Swinging doors must be located adjacent to revolving doors, and revolving doors must not be located at the foot of a stairway. Alternatively, specially designed electrically powered revolving doors are permitted for higher occupant capacities and without adjacent swinging doors.

EXTERIOR EXIT ACCESS

In the International Building Code, exterior access ways can serve as *egress balconies* when one of the long sides of the balcony is at least 50% open to the exterior. Egress balconies leading to only one exit stair must be separated from interior spaces by rated walls and protected door and window openings with fire ratings equal to those required for corridors. Where such balconies have two ways off, adjacent walls, windows, and doors are not required to be fire rated, provided that from any point on the balcony, a fire burning through any one door or window cannot simultaneously block an occupant's access to both ways off the balcony. When designing with egress balconies, this code permits allowable travel distances (pages 271–272) to be increased by the length of the balcony, up to100 ft (30 m) maximum. Egress balconies must be at least 10 ft (3.0 m) from adjacent buildings or lot lines (measured perpendicular to the outer edge of the balcony).

The National Building Code of Canada treats exterior passageways as exits rather than exit access. They must be separated from the interior of the building in the same manner as conventional interior exits, unless one side of the passageway is at least 50% open to the exterior, and exit stairs are provided at both ends of the passageway, in which case no separation is required.



EXTERIOR CORRIDOR OR EXIT PASSAGEWAY

OTHER EXIT ACCESS REQUIREMENTS

The model building codes contain many additional provisions relating to unique egress provisions for specific Occupancy conditions, illumination of exit access facilities, marking of exit paths, combustibility of finish materials in exit access corridors, alarm systems, door operation and hardware, and other safety concerns. Consult the appropriate code for more information.

EXITS

The exit is the portion of the means of egress following the exit access that is designed to provide significant protection to building occupants. Exits must be enclosed within fire-resistant rated assemblies, cannot be used for purposes other than egress, and must be continuous until they discharge from the building. With only a few, narrow exceptions, once building occupants enter an exit stairway or exit passageway, they must be able to reach the exterior of the building without passing through spaces with a lower level of protection or intended for other uses.

In most circumstances, each floor of a building must have at least two independent exits. Wherever more than one exit is required, the capacity of the exits should be balanced so that the loss of any one will not reduce the remaining egress capacity to less than one-half of the total required.

International Building Code

For most buildings, each floor or occupied roof with 500 or fewer occupants must have at least two independent exits. Levels with between 501 and 1000 occupants must have at least three such exits, and levels with more than 1000 occupants must have at least four. Where multiple exits are required, they must be arranged to meet the remoteness requirements described on page 271. For special requirements for additional exits in tall buildings, see page 297.

Single-Exit Floors: Certain Occupancies are permitted to have only one exit from a floor. For a floor at grade or the uppermost level of a basement below grade, one exit is permitted for the following:

Occupancies	Maximum Occupants	Maximum Travel Distance
A, B, E, F, M, U	49	75 ft (23 m)
B, F; building fully sprinklered	49	100 ft (30 m)
I	10	75 ft (23 m)
R; building fully sprinklered	10	75 ft (23 m)
S, unsprinklered and excluding open parking	29	75 ft (23 m)
S, fully sprinklered building or open parking	29	100 ft (20 m)

For second stories, one exit is permitted for the following:

Occupancies	Maximum Occupants	Maximum Travel Distance
B, F, M	29	75 ft (23 m)
S, excluding open parking	29	75 ft (23 m)
S, open parking	29	100 ft (20 m)

Certain other Residential Occupancy conditions in fully sprinklered buildings are also permitted one exit:

- Any R-3 or R-4 Occupancy
- Not more than four R-2 dwelling units, on a first-, second-, or third-floor level, or uppermost basement level, with a common path of egress travel not exceeding 125 ft (38 m)

Note that where single-exit floors are permitted and the travel distance maximums in the previous two tables are met, common path of egress travel limitations (page 272) do not apply.

National Building Code of Canada

Most buildings must have at least two independent exits from each floor. Floors of one- or two-story buildings may have only one exit if they have not more than 60 occupants and do not exceed the floor area and travel distance limits in the following table. In the case of B Care, Treatment, or Detention and C Residential Occupancies (other than dwelling units), such exits must open directly to the exterior, without enclosed stairways, not more than 1.5 m (5 ft) above the adjacent ground level.

Individual dwelling units within Residential Occupancies are permitted to have just one means of egress when:

- A single exit door leads directly to the exterior not more than 1.5 m (5 ft) above grade, and
- The exit door is within one story of every floor level within the unit, or the uppermost floor of the unit opens to an exterior balcony that is not more than 6 m (20 ft) above grade.

A-3 Open Air Assembly Occupancy tiers or balconies with between 1001 and 4000 occupants must have at least three exits, and those with more than 4000 occupants must have at least four exits.

NATIONAL BUILDING CODE OF CANADA: FLOORS WITH SINGLE EXITS

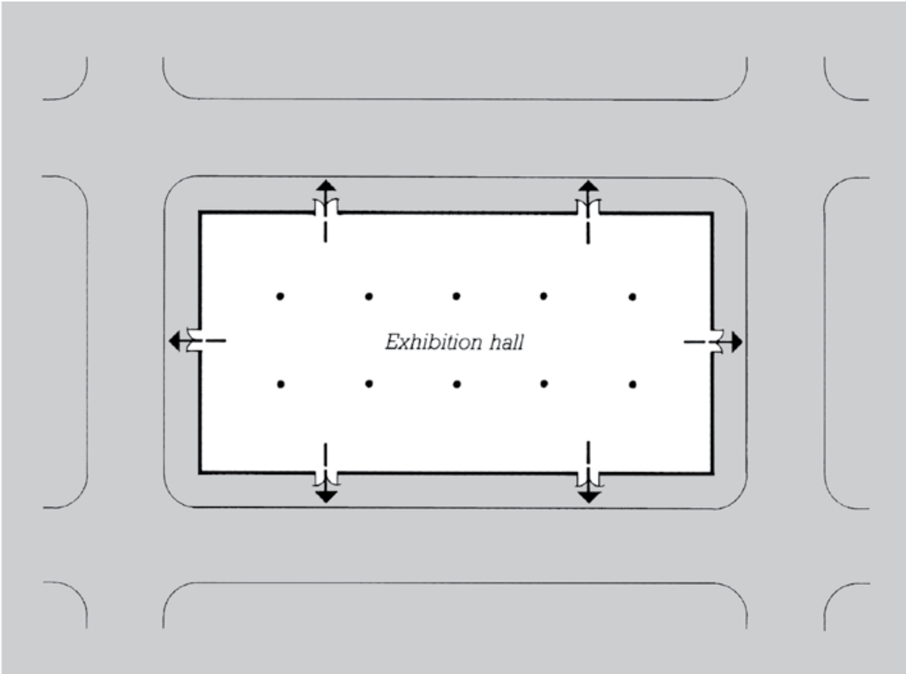
	Unsprinklered		Sprinklered	
Occupancy	**Maximum Floor Area**	**Maximum Travel Distance**	**Maximum Floor Area**	**Maximum Travel Distance**
A: Assembly	150 m^2 (1615 ft^2)	15 m (49 ft)	200 m^2 (2150 ft^2)	25 m (82 ft)
B: Care, Treatment, or Detention	75 m^2 (805 ft^2)	10 m (33 ft)	100 m^2 (1075 ft^2)	25 m (82 ft)
C: Residential	100 m^2 (1075 ft^2)	15 m (49 ft)	150 m^2 (1615 ft^2)	25 m (82 ft)
D: Business and Personal Services	200 m^2 (2150 ft^2)	25 m (82 ft)	300 m^2 (3330 ft^2)	25 m (82 ft)
E: Mercantile	150 m^2 (1615 ft^2)	15 m (49 ft)	200 m^2 (2150 ft^2)	25 m (82 ft)
F-2: Industrial, Medium-Hazard	150 m^2 (1615 ft^2)	10 m (33 ft)	200 m^2 (2150 ft^2)	25 m (82 ft)
F-3: Industrial, Low-Hazard	200 m^2 (2150 ft^2)	15 m (49 ft)	300 m^2 (3330 ft^2)	25 m (82 ft)
Occupied Roofs	Two exits required if occupant load is greater than 60			

DIRECT EXITS

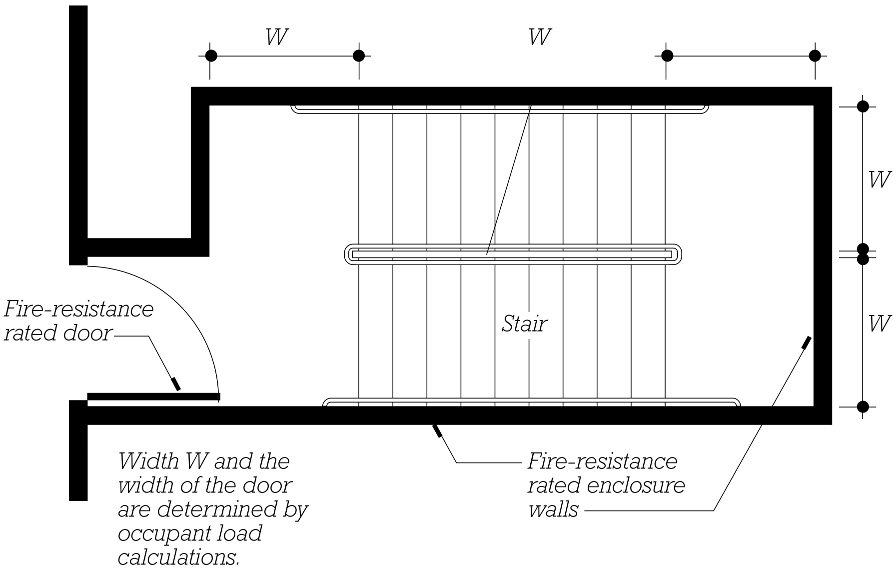
The simplest type of exit is a door opening directly from an interior room or space to the exterior, as might occur from a grade-level exhibition hall, theater, gymnasium, or classroom. Exit doors of this type do not normally need to have a fire-resistance rating.

EXIT STAIRWAYS

Enclosed stairways are the most common form of exit component. Minimum required widths for stairways and landings depend on the Occupancy and the number of occupants served. See pages 306–307 for the International Building Code and pages 312–313 for the National Building Code of Canada. Dimensions and typical designs for stairways and stair enclosures are provided on pages 321–331. For provisions allowing open stairways, see page 274.



DIRECT EXITS



EXIT STAIRWAYS

International Building Code

The International Building Code requires exit stairways serving four stories or more to be enclosed within 2-hour fire-resistance rated construction with 1½-hour self-closing doors opening from each floor into the stairway. Enclosures of stairways serving fewer than four floors may be of 1-hour rated construction, with 1-hour self-closing doors. However, exit enclosures penetrating floors with a fire-resistance rating of 2 hours or more must also be 2-hour rated, regardless of the number of stories served. Exit enclosure doors opening to the exterior are not required to be rated. Exit enclosures are not required for:

- Stairways not counted as a part of the required means of egress
- Exit stairways within dwelling or sleeping units of Group R-1, R-2, or R-3 Occupancies
- Exit stairways in open parking garage structures or open arenas
- Exit access stairways as discussed on page 274

Doors in exit enclosures serving an occupant load of 50 or more must swing in the direction of egress travel. So-called *scissor stairs*, in which two intertwined stairways are contained within a single enclosure, are considered to be only a single exit stairway.

National Building Code of Canada

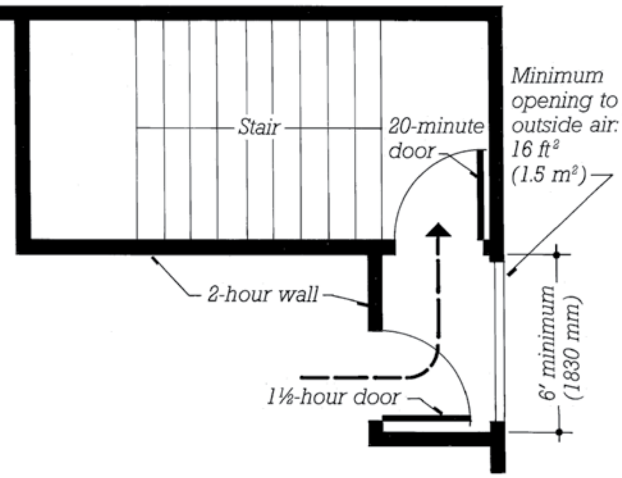
The National Building Code of Canada requires the construction of an exit stairway enclosure to match the fire resistance of the floor assembly directly above that enclosure or, if there is no floor above, that of the floor below. However, the rating of the enclosure need never exceed 2 hours, and it may never be less than ¾ hour. Doors opening into the stairway must be self-closing, and in 2-hour enclosures must be 1½-hour rated; in 1½-hour enclosures, 1-hour rated; and in 1-hour or ¾-hour enclosures, ¾-hour rated.

SMOKEPROOF ENCLOSURES

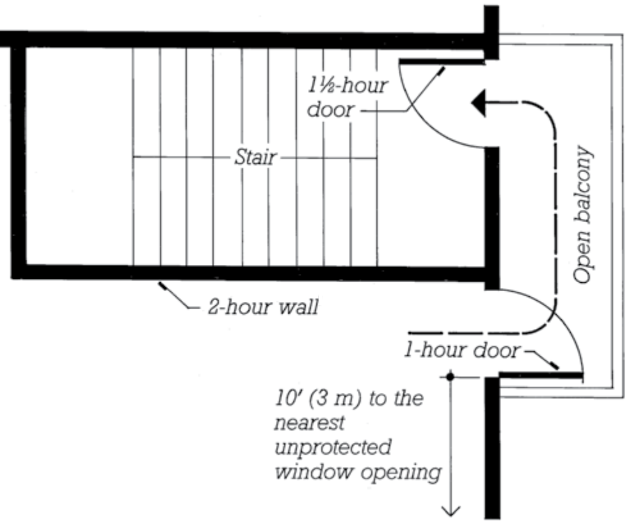
Exit stair enclosures in tall buildings must be designed as *smokeproof enclosures*, to provide a greater degree of protection from smoke entering the stair enclosure during a fire emergency. In the International Building Code, these requirements apply to high-rise buildings as well as to buildings with significant underground occupancy. The National Building Code of Canada has similar requirements, most commonly applicable to buildings with occupied floors more than 18 to 36 m (59 to 188 ft) above grade, depending on the type of Occupancy. For additional information about high-rise building requirements, see High-Rise Buildings, page 297, for the International Building Code, and High Buildings, page 298, for the National Building Code of Canada.

Smokeproof enclosures may rely on naturally ventilated vestibules or open exterior balconies that allow smoke on a fire-engaged floor to escape to the exterior before reaching the stairway. Vestibules may also rely on mechanical systems for smoke exhaust. See the accompanying illustrations. In fully sprinklered buildings, stairway enclosures may themselves be mechanically pressurized to deter smoke from entering the stairway, in which case intervening vestibules or balconies are not required (not illustrated).

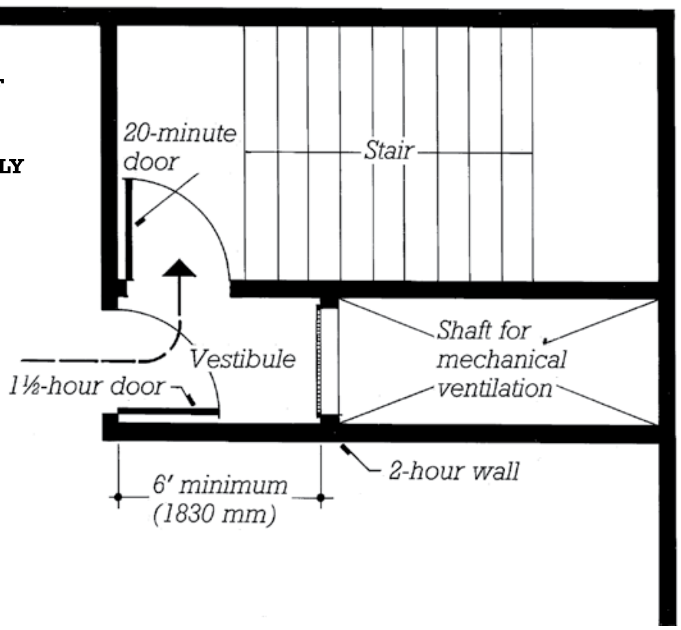
SMOKEPROOF ENCLOSURE WITH A NATURALLY VENTILATED VESTIBULE



SMOKEPROOF ENCLOSURE WITH AN OPEN EXTERIOR BALCONY



SMOKEPROOF ENCLOSURE WITH A MECHANICALLY VENTILATED VESTIBULE



EXTERIOR STAIRWAYS AND FIRE ESCAPES

Exterior stairways, separated from the building interior by exterior walls but open to the outside, are considered part of the exit portion of the egress system. Traditional open metal fire escapes are not permitted as exits except in very limited circumstances.

International Building Code

In the International Building Code, exterior stairways may serve as part of the egress system in buildings up to six stories in height, with the highest occupied floor not more than 75 ft (23 m) above the lowest ground level, and for any Occupancy other than I-2. At least one side of the stairway must have a minimum open area of 35 sq ft (3.3 m^2) at each floor level. Exterior stairways must be constructed with solid treads (as distinct from open gratings), and must not allow the accumulation of standing water.

In general, the exterior wall separating an exterior stairway from the interior of the building must provide the same level of protection as required for an interior exit stair enclosure (pages 382–383). However, for certain Occupancies, building heights, and egress path configurations, this requirement may be waived. An exterior stairway must remain at least 10 ft (3.0 m) from property lines and other portions of the building it serves (this distance measured at right angles to the stair). A 10-ft (3.0-m) fire separation distance must also be maintained from adjacent buildings on the same property, unless the walls of the adjacent building provide an adequate level of fire protection. (See page 381 for more information about fire separation distance.)

Traditional, open-grate fire escapes are permitted as a second exit in existing buildings where it is impractical to construct a second stair meeting current code requirements.

National Building Code of Canada

In the National Building Code of Canada, treads and landings more than 10 m (33 ft) above grade must be protected from snow or ice accumulation. This code also permits fire escapes as a second exit in existing buildings where other forms of exit are impractical. Such fire escapes may serve up to two stories above ground for B Treatment, Care, or Detention Occupancies, or up to five stories above ground, serving other Occupancies.

ELEVATORS

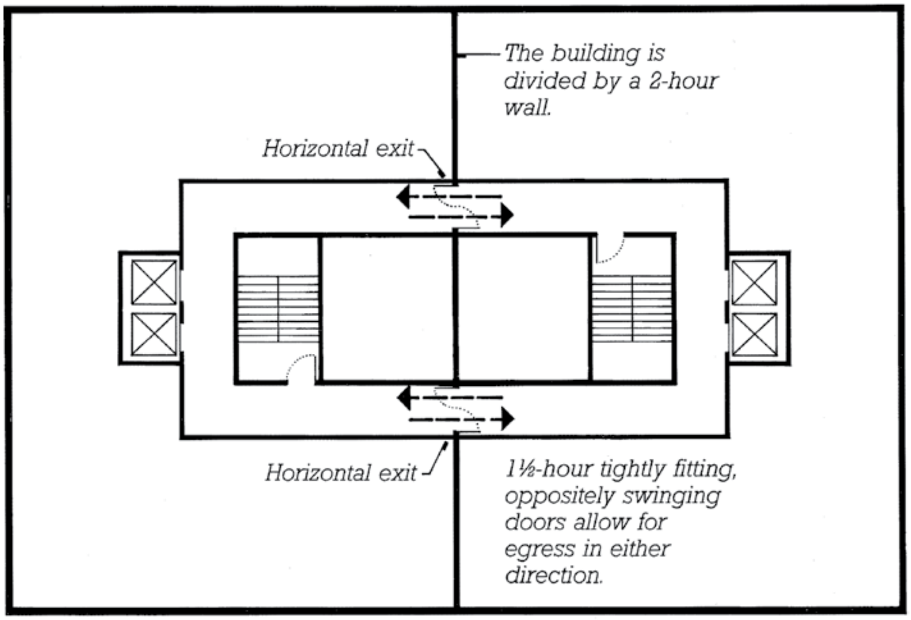
Conventional elevators may not serve as parts of the building egress system. However, in the International Building Code, they may be used as parts of the accessible means of egress for disabled persons (see pages 288–289).

In the International Building Code, *occupant evacuation elevators*, made especially resistant to fire, smoke, and water from fire sprinklers, may be used to provide added egress capacity in tall buildings. These elevators may not replace required egress stairways, except in high-rise buildings, where they may be used as a replacement for the required extra exit stairway (see page 297).

REFUGE AREAS AND HORIZONTAL EXITS

A *refuge area* is a protected area within a building or an adjacent building to which occupants can retreat—without reliance on stairways—to escape the dangers of fire. Such areas are required in care facilities where, in the case of emergency, patients requiring assistance or who are bedridden must be moved to safety, and in detention facilities where it is not practical to allow occupants unrestricted freedom to exit a building. Refuge areas are sometimes used in tall buildings, allowing larger numbers of occupants to escape the immediate danger of fire more quickly than would be possible using only exit stairways.

In the International Building Code, I-2 Medical and Custodial Care and I-3 Detention and Security Occupancy floors must be subdivided into at least two distinct refuge areas wherever floors include sleeping units or treatment areas, or have an occupant load of 50 or more. Such areas are separated from surrounding spaces by smoke barriers (wall and floor assemblies resistant to the passage of smoke but not necessarily having a fire-resistance rating). Each refuge area must provide access to a second independent means of egress. In I-2 Occupancies, the refuge area occupant capacity is calculated as 6 sq ft (0.56 m^2) per ambulatory occupant and 30 sq ft (2.8 m^2) per nonambulatory (bedridden) occupant. The maximum permitted area for individual refuge areas varies depending on particulars of the Occupancy conditions. In I-3 Occupancies, refuge area capacity is calculated as 6 sq ft (0.56 m^2) per person, and any individual area occupant capacity cannot exceed 200 persons. As an alternative to



HORIZONTAL EXITS

providing separate refuge areas in I-3 Occupancies, residents may be provided with direct access to a public way, separate building, or secured yard or court.

In the National Building Code of Canada, B-2 Medical Treatment and B-3 Care Occupancy floors must be subdivided into two or more refuge areas wherever floors include sleeping or patient rooms for 10 or more patients or residents. Refuge areas are separated from adjacent spaces by wall and floor assemblies with a fire-resistance rating of 45 minutes to 1 hour. Each refuge area must provide access to a second independent means of egress. Occupant capacity is calculated as 1.5 m^2 (16 sq ft) per wheelchair occupant, 2.5 m^2 (27 sq ft) per bedridden occupant, and 0.5 m^2 (5.4 sq ft) per person for other occupants. Individual refuge areas cannot exceed 1000 m^2 (10,765 sq ft) in area. In addition, operating rooms, recovery rooms, delivery rooms, and intensive care units where patients cannot easily be moved must be separated from other areas by wall and floor assemblies with a 1-hour fire-resistance rating, and protected from smoke infiltration by a dedicated mechanical air supply system.

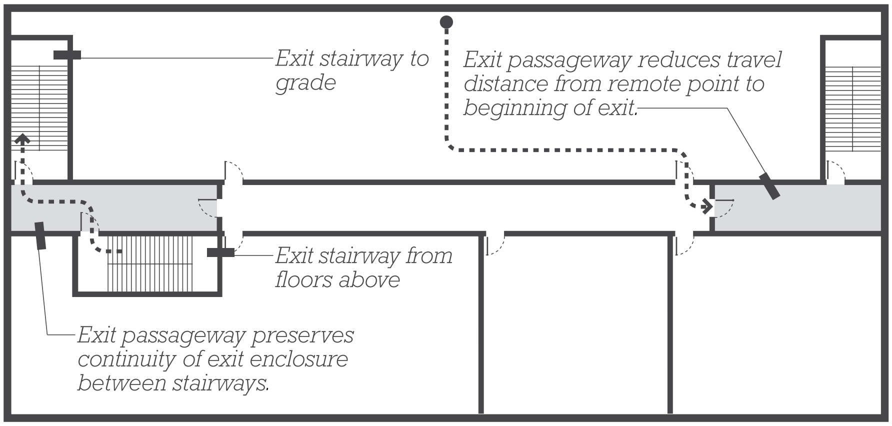
Both model codes also permit horizontal egress through fire-resistance rated walls to refuge areas in separate parts of the same building or in an adjacent building. Such *horizontal exits* are normally permitted to provide up to one-half of the required exit capacity of a story (or more, in certain Medical, Care, and Detention Occupancies). The refuge area must have sufficient capacity to accommodate its own occupants plus the added occupants arriving through the horizontal exit, and it must have at least one additional independent means of egress. In the International Building Code, horizontal exits may be separated by 2-hour fire-rated partitions or more secure *fire walls*. In the National Building Code of Canada, 2-hour rated fire walls are required. For more information on fire wall requirements, see page 381.

In other than the Care, Treatment, and Detention Occupancies noted, refuge area occupant capacity is calculated as 3 sq ft (0.28 m²) per person in the International Building Code, and as 0.5 m² (5.4 sq ft) per person in the National Building Code of Canada. Private spaces inaccessible to occupants arriving through the horizontal exit should not be included in these calculations.

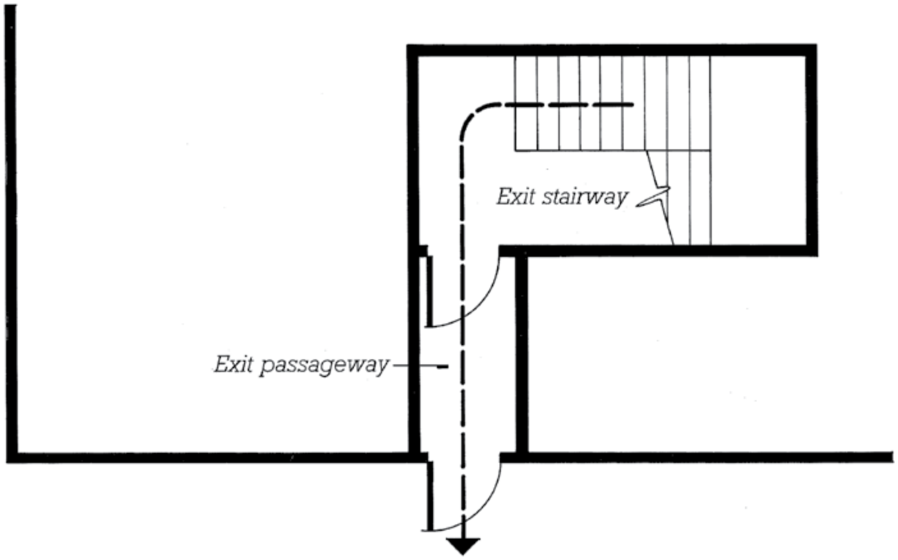
A horizontal exit may be designed to function for travel in one direction only, as in the case of a building that has one exit stairway and a horizontal exit to an adjoining building that has two or more exit stairways. In this case, the corridors and lobbies of the adjoining building serve as the refuge area for the first building. Or a horizontal exit may be designed to function for travel in both directions, as shown in the accompanying illustration. In this case, the corridor on each side of the exit serves as an area of refuge for the occupants on the other side.

EXIT PASSAGEWAYS

An *exit passageway* is a horizontal portion of the means of egress that is protected from fire in the same manner as an enclosed exit stair. An exit passageway has several uses: It may be used to preserve the continuity of enclosure for an exit stair whose location shifts as it descends through the building, to eliminate excessive travel distance within a floor, or to connect the bottom of an enclosed stairway to a remotely located exterior exit doorway. Exit passageways must meet the same width requirements as corridors, as tabulated on pages 307 and 313.



EXIT PASSAGEWAYS



EXIT DISCHARGE THROUGH AN EXIT PASSAGEWAY

OTHER EGRESS COMPONENTS

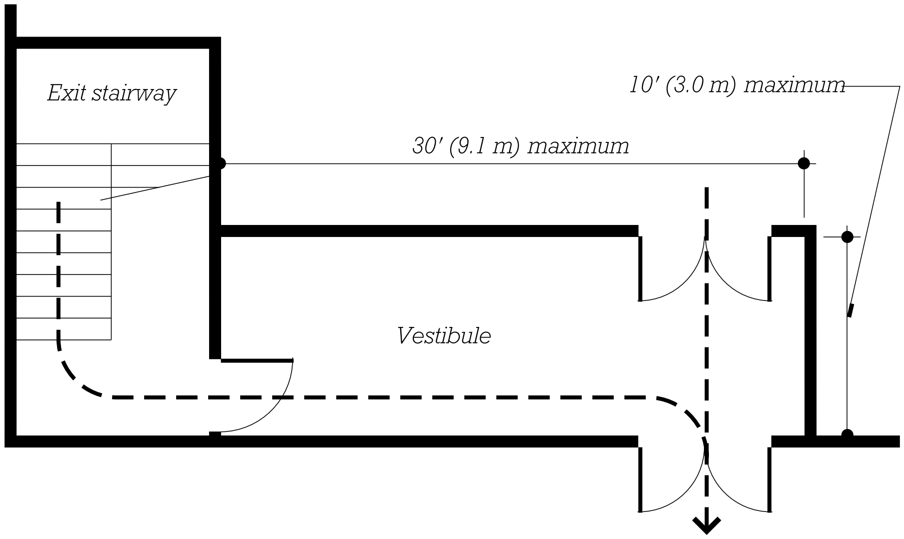
Moving stairways, or escalators, may not serve as components of building egress systems. Nor may escape slides, poles, or rope ladders.

In the International Building Code, alternating tread stairs and ships ladders are permitted as means of egress components in limited industrial, storage, or I-3 Occupancy supervision applications.

THE EXIT DISCHARGE

The exit discharge connects the exit to the public way or to some other place of safety. It may include both exterior and limited interior components.

In the International Building Code, when courts or yards serving as part of the exit discharge are less than 10 ft (3.0 m) wide, building walls abutting the court must be 1-hour fire resistance rated, and openings in the walls ¾-hour rated, for a height of at least 10 ft (3.0 m) above the court level (except R-3 Occupancies and courts serving fewer than 10 occupants). Where access to a public way cannot be provided, exits may discharge to a dispersal area on the same property located at least 50 ft (15 m) from the building and providing at least 15 sq ft (1.4 m^2) of space per person.



EXIT DISCHARGE THROUGH A VESTIBULE

LOBBIES AND VESTIBULES

Both model codes permit some portions of exits to discharge through interior areas.

The International Building Code permits up to 50% of a building's required egress capacity to discharge through open areas or vestibules on the ground-floor level of a building. For areas such as lobbies:

- The egress pathway must be readily identifiable.
- The entire floor level must be separated from levels below by construction with a fire-resistance rating at least equal to that required for the exit enclosure.
- The entire floor must be sprinklered, or unsprinklered portions must be separated from the exit discharge area by walls with the same fire-resistance rating as that required for the exit.

Vestibules must be dedicated solely to egress, limited in dimension as indicated on the accompanying diagram, separated from levels below by construction with a fire-resistance rating equal to that required of the exit, and separated from the remainder of the building by the equivalent of ¾-hour fire-resistance rated partitions or glazing.

The National Building Code of Canada permits no more than one exit to pass through a lobby, provided that:

- The lobby floor is not more than 4.5 m (148 ft) above grade.
- The path of travel through the lobby to the exterior does not exceed 15 m (49 ft).
- The lobby does not provide direct access to B-3 Care, C Residential, or F Industrial Occupancies.
- The lobby is not part of an interconnected floor space (see page 379), except as permitted for exit stairs.
- The remainder of the exit is separated from the lobby by a standard exit enclosure.
- The lobby is separated from other areas by assemblies with the same rating required for an exit enclosure, except that, if the floor is fully sprinklered, separations do not require a fire-resistance rating.

The goal of accessibility legislation in the United States and Canada is to provide people with physical, cognitive, or sensory limitations the broadest possible access to most types of buildings, including, for example, government buildings, schools, houses of worship, retail establishments, places of business, public and private transportation facilities, bars, restaurants, hotels, multifamily housing, places of entertainment and culture, recreational facilities, and places of work. Buildings and their surroundings must provide continuous, unobstructed routes by which such persons can park their vehicles or disembark from public transportation, approach the building, enter, reach virtually any point in the building, and gain access to the same amenities and activities available to others, such as dwelling units, community spaces, spectator seating, retail counters, ticket windows, toilet and washroom fixtures, drinking fountains, public telephones, and so forth.

This section summarizes accessibility requirements of the two model building codes as they affect the form and organization of buildings. It does not address all technical requirements of these codes. Nor does it address requirements of other federal, provincial, state, or local accessibility regulations that may apply. Be sure to consult the building code and other relevant regulations as your building design progresses.

Other aspects of accessible design are addressed elsewhere in this book: For accessible wheelchair space requirements in Assembly seating areas, see page 296; for accessibility requirements for toilet and bathing facilities, see pages 202 and 204; and for accessible parking requirements, see pages 340–341.

ACCESSIBLE DESIGN IN THE INTERNATIONAL BUILDING CODE

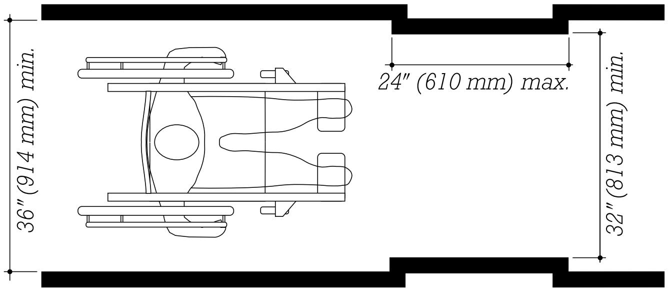
In the International Building Code, most buildings and spaces are required to be made accessible for persons with physical disabilities. Exceptions include the following:

- Detached one- and two-family dwellings
- Most U Occupancy Utility and Miscellaneous buildings
- R-1 Occupancy hotel and motel buildings when owner-occupied and containing not more than five sleeping units
- Raised or depressed areas of limited size in places of worship
- Certain common-use portions of detention and correctional facilities when not serving accessible detainee cells
- Single-occupant structures, such as toll booths, accessed primarily by underground tunnels or overhead walkways
- Raised areas used for security and life safety, such as guard towers or observation galleries
- Equipment spaces, service spaces, walk-in coolers and freezers, and limited-access spaces

Accessibility requirements for employee work areas are generally limited to common circulation paths, such that persons with disabilities can enter and exit the work area. Where an exempt residential structure includes day care or live/work facilities, only the care or nonresidential portions of the structure must be made accessible.

Accessible Entrances and Routes

Where a building is required to be accessible, its main entrance and not less than 60% of all of its public entrances must be accessible, and at least one accessible route must lead to each accessible portion of the building. Accessible routes must coincide with and be located in the same areas as other circulation. Where general circulation is interior, accessible routes must be interior as well. Where only one accessible route is provided, it may not pass through kitchens, storage rooms, restrooms,



INTERNATIONAL BUILDING CODE ACCESSIBLE CORRIDOR

or other such ancillary spaces. However, in dwelling units, a single accessible route may pass through a kitchen or storage room.

In multilevel buildings, an accessible route must connect each level, including mezzanines, except:

■ Levels themselves not required to be accessible

■ In nongovernmental buildings, floors and mezzanines above and below accessible levels, totaling not more than 3000 sq ft (280 m^2) in area, where such floors do not contain offices of health-care providers, passenger transportation facilities, or five or more M Occupancy tenant spaces. (This exempts only the accessible route connecting the level to others. It does not exempt the spaces and facilities on the level itself from accessible design.)

■ In two-story buildings, a single story with an occupant load of five or less and not containing public use space

Key dimensional criteria in the design of accessible routes include the following:

■ Corridors, passages, and doorways without doors must be at least 36 in. (915 mm) wide. Projections not more than 24 in. (610 mm) in length, and spaced at least 48 in. (1220 mm) apart, may reduce the passage width to not less than 32 in. (815 mm).

■ Walking surfaces, except for ramps, may not be sloped greater than 1:20.

■ Doorway openings must have a minimum 32-in. (815-mm) clear width.

■ Latch side clearance for manually operated doors varies from 12 in. (305 mm) to 42 in. (1065 mm), depending on the manner in which the door is approached. When directly approaching a door opening on its pull side, 18 in. (445 mm) is required.

■ The minimum diameter of a wheelchair turning circle is 60 in. (1525 mm).

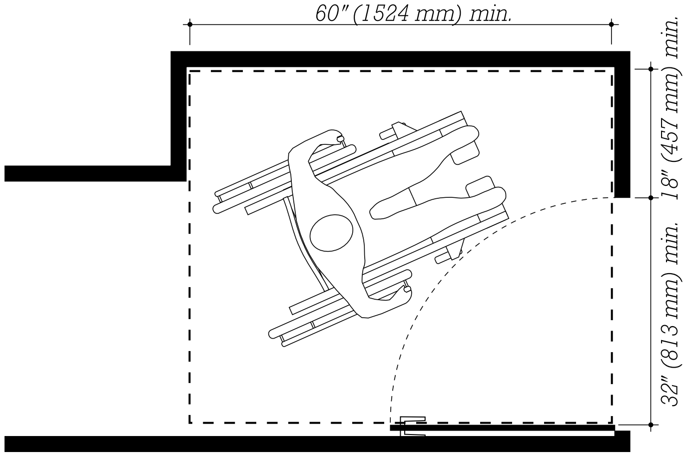
■ Ramps may not slope greater than 1:12, must have a minimum clear width of 36 in. (915 mm) between handrails, and may not rise more than 30 in. (760 mm) between landings. Landings must be at least 60 in. (1525 mm) in length.

Elevator car minimum clear inside dimensions vary with the size and position of the elevator car door:

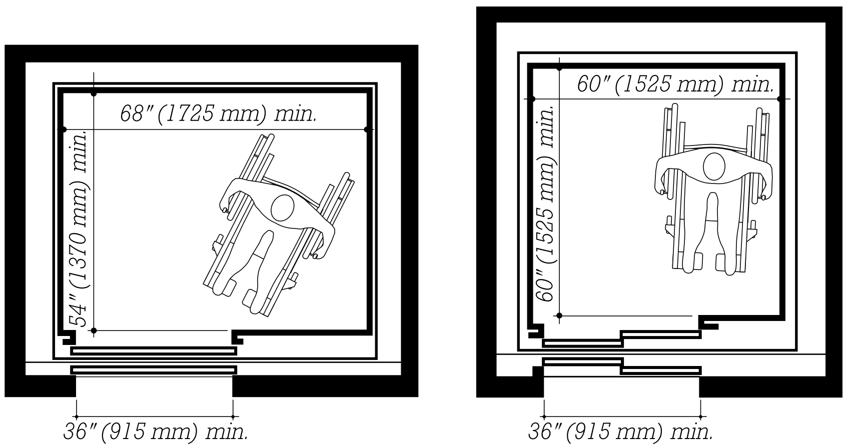
■ With a 36-in. (915-mm) clear door opening in any location: 60 in. (1525 mm) wide by 60 in. (1525 mm) deep, or 54 in. (1370 mm) wide by 80 in. (2030 mm) deep

■ With a 36-in. (915-mm) clear door opening, offset to one side: 68 in. (1725 mm) wide by 51 in. (1295 mm) deep

■ With a 42-in. (1065-mm) clear door opening, centered: 80 in. (2030 mm) wide by 51 in. (1295 mm) deep



INTERNATIONAL BUILDING CODE EXAMPLE OF AN ACCESSIBLE DOORWAY AND APPROACH



INTERNATIONAL BUILDING CODE AND NATIONAL BUILDING CODE OF CANADA EXAMPLE ACCESSIBLE ELEVATORS

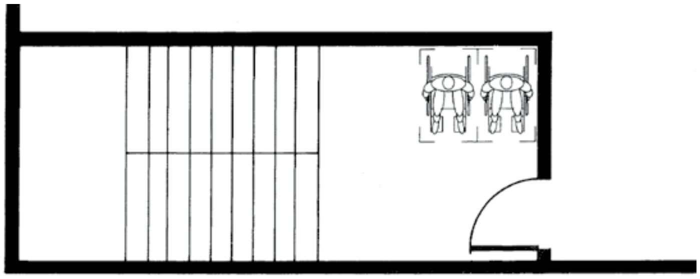
Although not strictly speaking an accessibility requirement, where one or more elevators are provided in a building with floors four or more stories above or below grade-level access, the International Building Code requires that at least one elevator serving all stories be large enough to accommodate a medical stretcher 24 in. (610 mm) wide and 84 in. (2134 mm) long, with its attendants. The code does not specify minimum car dimensions. For preliminary design purposes, an interior elevator cab size of 80–92 in. (2032–2337 mm) wide by 64 in. (1626 mm) deep may be assumed.

Wheelchair lifts are permitted to be part of accessible routes when serving performance areas, speaker platforms, assembly space wheelchair spaces, private areas with an occupant load of not more than five, spaces within living units, jury boxes, judges' benches, and other limited-use courtroom areas.

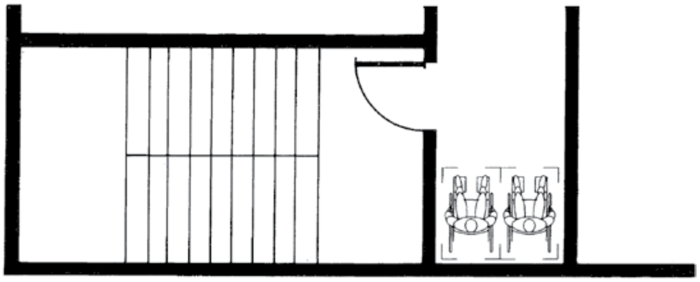
Accessible Means of Egress

Wherever spaces are accessible, at least one accessible means of egress (accessible exit route) must also be provided. Where two or more conventional means of egress from any area are required, there must be at least two accessible means of egress. Such means of egress may include typical accessible routes, such as level aisles and corridors, accessible ramps, horizontal exits, refuge areas, and appropriately designed elevators, as well as, in many cases, some egress stairways. Accessible mezzanines are permitted to have only one accessible means of egress, consisting of either an accessible stairway (see the following paragraph), elevator, or platform lift. Assembly areas with ramped or stepped aisles may have only one accessible means of egress.

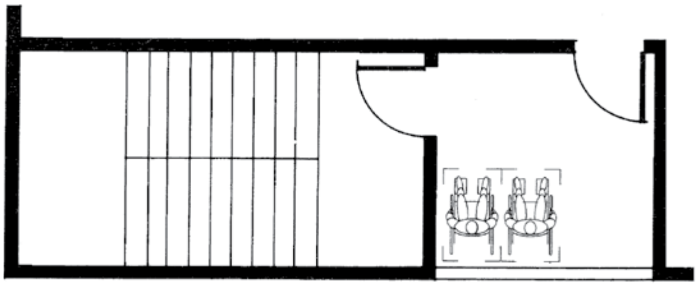
Most buildings with accessible floors above or below grade rely on exit stairways as one of the required accessible means of egress. In unsprinklered buildings, these stairways must be at least 48 in. (1219 mm) in clear dimension between the handrails, meaning that the overall width of the stair must be approximately 56 in. (1400 mm), and a small *area of refuge* (see the following paragraphs) must be provided within the stair enclosure or directly connected to the enclosure. In fully sprinklered buildings or where the stair is accessed from a horizontal exit, these special width and area of refuge requirements do



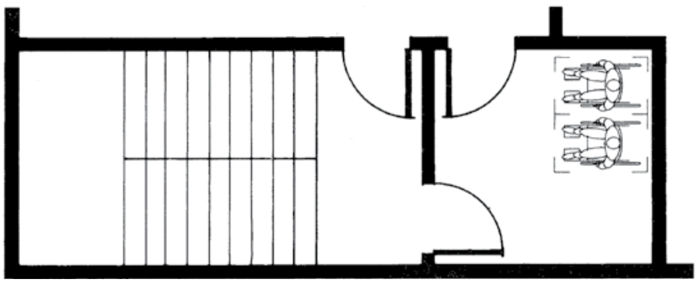
AREA OF REFUGE ON AN ENLARGED STAIRWAY LANDING



AREA OF REFUGE IN A 1-HOUR CORRIDOR



AREA OF REFUGE ON AN OUTDOOR BALCONY



AREA OF REFUGE IN A STAIRWAY VESTIBULE

not apply. An area of refuge is also not required when a two-way communication system is provided at an elevator entrance on the same floor, or when the stairway serves any of an open parking garage, smoke-protected assembly seating, or R-2 Occupancy space. Open exit access stairways between separate floors or serving mezzanines may be used as accessible means of egress. However, open stairways connecting level changes within a single floor may not.

In buildings with accessible floors four or more stories above or below grade, at least one accessible means of egress must consist of an elevator with a secure power supply. Alternatively, in a fully sprinklered building, floors above ground level may be served by horizontal exits (page 283) instead of an elevator. Fully sprinklered sports stadiums or other structures with accessible ramps serving each level are also exempt from this requirement. Where elevators are used, they must be provided with an area of refuge unless (1) the building is fully sprinklered, (2) the elevator is accessed from a horizontal exit, (3) the elevator itself does not require an enclosed shaft, or (4) the elevator serves either smoke-protected assembly seating or an open parking garage.

Where required, an area of refuge must have direct access to the stairway or elevator it serves. It must be clearly identified with visual and tactile signage within the enclosure, protected from smoke, provided with instructions for use, and provided with two-way electronic communications with the primary entry point of the building. Maximum travel distance to the nearest area of refuge must not exceed the limits on page 306.

Areas of refuge may be constructed in a variety of ways: as enlarged floor-level landings within a stairway enclosure, areas within a rated corridor, outdoor balconies leading to an exit stairway, enclosed vestibules, or elevator lobbies constructed as smokeproof enclosures. A wheelchair space 30 × 48 in. (760 × 1220 mm) must be provided for every 200 occupants on each floor. These refuge spaces must not encroach into the required egress paths, and where multiple spaces are required, wheelchairs cannot be stacked more than two deep.

Accessible Dwelling and Sleeping Units

In the International Building Code, accessibility requirements for sleeping and dwelling units apply to the following Residential Occupancies:

- Hotels and motels
- Apartment buildings and condominiums
- Nursing homes and assisted living facilities
- Boardinghouses, residential hotels, and motels
- Hospices and homeless shelters
- Corporate housing, dormitories, and migrant worker housing
- Seasonal vacation units and timeshare units
- Residential structures comprising four or more dwelling or sleeping units

Where accessibility requirements apply, dwelling or sleeping units must achieve one of three levels of accessibility. *Accessible units* meet all clear space and maneuverability requirements for wheelchair navigation and provide fully accessible work surfaces, fixtures, and equipment. *Type A units* must meet the same wheelchair clear space and maneuverability requirements as Accessible units. However, other elements, such as special-height work surfaces and toilet room grab bars, are not required in this unit type as long as provision is made for their installation at a later date. *Type B units* provide the lowest level of accessibility. Wheelchair maneuverability requirements are less stringent, and some parts of units (for example, sunken living rooms or mezzanine-level bedrooms) need not be accessible.

Accessible Units: For Accessible unit requirements, see the table on this page. For Occupancy Group R-1, requirements should be based on the total number of sleeping or dwelling units on a site, even when these units are contained in multiple detached buildings.

Type A Units: Group R-2 Residential buildings not required to provide Accessible units are subject to Type A unit requirements. This includes apartment houses constructed without federal government funding, monasteries, and convents. When they contain more than 20 dwelling or sleeping units, at least 2% but never less than one unit in these building types must be Type A.

Type B Units: In the following Occupancy type buildings, where one building or multiple attached buildings contain four or more dwelling or sleeping units combined, all such units that are not Accessible or Type A must meet the requirements of Type B units: Groups I-1, I-2, R-2, R-3, and R-4.

This requirement also applies to Group R-1 hotels and motels to the extent that units in these buildings are occupied as permanent or semipermanent residences, rather than as transitory accommodations. For example, where rooms in a hotel or motel are conventionally let out to overnight or short-term guests, Type B unit requirements do not apply. However, where such units may be used for extended-stay housing or as seasonal vacation units, they are considered occupied as residences, and compliance with Type B unit requirements is mandatory. Any sleeping accommodation occupied continuously for more than 30 days should be considered occupied as a residence.

Where residential buildings do not have elevator service to all floors, or where site impracticality limits accessibility, a reduction in the number of required Type A or B units may be permitted.

Occupancy	Minimum Number of Accessible Units
Group I-1 supervised residential facilities	
With occupants capable of responding independently to a building emergency	4%, but not less than 1
With occupants requiring limited assistance in the event of a building emergency.	10%, but not less than 1
Group I-2 nursing homes	50%, but not less than 1
Group I-2 hospitals and rehabilitation facilities	10%, but not less than 1
Group I-2 hospitals and rehabilitation facilities specializing in the treatment of patients with impaired mobility	100%
Group I-3 detention and security facilities	3%, but not less than 1
Group R-1 hotels and motels, and Group R-2 boardinghouses, dormitories, fraternity houses, sorority houses, and any other facilities constructed with federal government funding	
With 1 to 25 units total	1
With 26 to 50 units total	2
With 51 to 75 units total	4
With 76 to 100 units total	5
With 101 to 150 units total	7
With 151 to 200 units total	8
With more than 200 units total	Approximately 3%; see the code for exact numbers
Group R-2 apartment houses and condominiums constructed without federal government funding, monasteries, and convents	None (see Type A unit requirements in the text)
Group R-3 one- and two-family residences and townhouses	None
Group R-4 assisted living facilities	1
With occupants capable of responding independently to a building emergency	1
With occupants requiring limited assistance in the event of a building emergency.	2

ACCESSIBLE DESIGN IN THE NATIONAL BUILDING CODE OF CANADA

The National Building Code of Canada requires all buildings to be accessible except:

- Single-family residences, including detached and semidetached houses, duplexes, triplexes, townhouses, row houses, boarding-houses, and secondary suites in one- or two-family houses
- Buildings with Group F-1 High-Hazard Industrial as their principal Occupancy
- Buildings not intended to be occupied daily or full-time, such as automatic telephone exchanges, pump houses, and electrical substations

Where a building is required to be accessible, its principal entrance, and not less than one-half of all of its pedestrian entrances, must be accessible. Accessible paths of travel must be provided throughout entrance stories and other normally occupied floor areas served by passenger elevators or other accessible means. Where escalators provide public access to multiple levels, alternative accessible means of access must be provided. Accessible paths of travel to the following locations are not required:

- Building service areas, crawlspaces, attics, rooftops, janitor's rooms, elevator machine rooms
- Floor levels not served by a passenger elevator, passenger-elevating device, escalator, or moving walk
- Mezzanines not served by passenger elevators or other accessible means
- Portions of fixed-seating floor areas within Assembly Occupancies not part of the path of travel to designated wheelchair spaces
- Portions of Residential Occupancy suites not at the entrance level
- Sunken or raised portions of floor areas not at the same level as the entrance level, provided that similar accessible amenities are provided at the entrance level
- F-1 High-Hazard Industrial Occupancy areas

Key dimensional criteria in the design of accessible routes include the following:

■ Corridors, passages, and doorways without doors must be at least 920 mm (36¼ in.) wide. Accessible paths longer than 30 m (98 ft) must provide a passing/turning space not less than 1500 mm (59 in.) square at intervals not exceeding 30 m (98 ft).

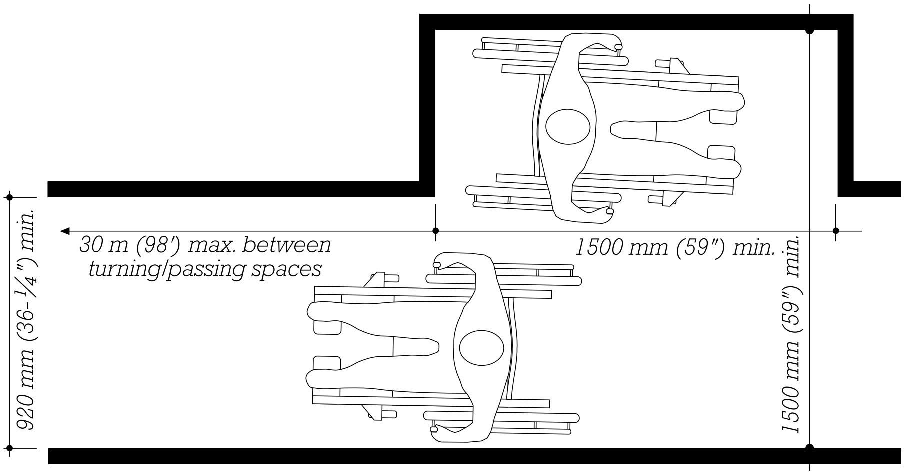
■ Walking surfaces, except for ramps, may not be sloped greater than 1:20.

■ Doorway openings must have a minimum 800-mm (31½-in.) clear width.

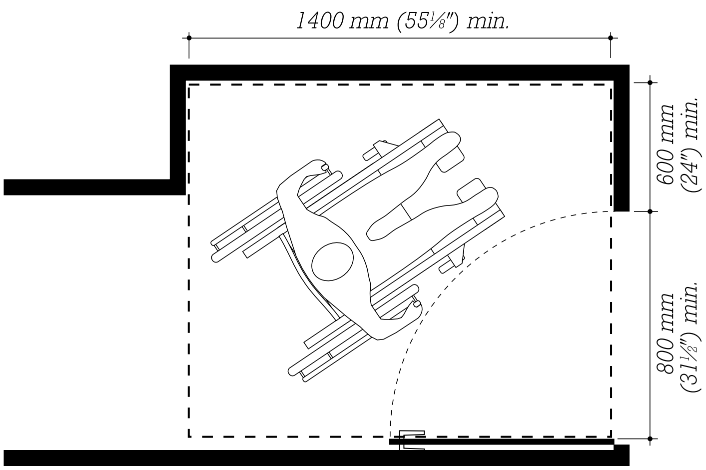
■ Latch side clearance for manually operated doors is 600 mm (24 in.) for doors swinging toward the approach side, and 300 mm (12 in.) for doors swinging away from the approach side.

■ The minimum diameter of a wheelchair turning circle is 1500 mm (59 in.).

■ Ramps may not slope greater than 1:12, must have a minimum clear width of 870 mm (34¼ in.) between handrails, and may not exceed a horizontal distance of 9 m (29 ft 6 in.) between landings. Landings at the top and bottom of ramps must be not less than 1500 mm (59 in.) square. At intermediate points within the ramp, landings must be at least as wide as the ramp and not less than 1200 mm (48 in.) in length.



NATIONAL BUILDING CODE OF CANADA ACCESSIBLE CORRIDOR



NATIONAL BUILDING CODE OF CANADA EXAMPLE OF ACCESSIBLE DOORWAY AND APPROACH

Elevator car minimum clear inside dimensions are identical to the requirements of the International Building Code and are repeated here for convenience. Minimum size requirements vary with the size and position of the elevator car door (see the illustrations on page 287):

■ With a 915-mm (36-in.) clear door opening in any location: 1525 mm (60 in.) deep by 1525 mm (60 in.) wide, or 2030 mm (80 in.) deep by 1370 mm (54 in.) wide

■ With a 915-mm (36-in.) clear door opening, offset to one side: 1295 mm (51 in.) deep by 1725 mm (68 in.) wide

■ With a 1065-mm (42-in.) clear door opening, centered: 1295 mm (51 in.) deep by 2030 mm (80 in.) wide

Although not strictly speaking a requirement for accessible access, where one or more elevators are provided in a building, the National Building Code of Canada also requires that at least one elevator serving all stories be large enough to accommodate a medical stretcher 610 mm (24 in.) wide and 2010 mm (79 in.) long, with its attendants. The code does not specify minimum car dimensions that satisfy this requirement but does provide the following examples of recommended configurations:

■ An elevator car with minimum clear interior dimensions of 2032 mm (80 in.) by 1295 mm (51 in.), with a 1067-mm (42-in.) clear door opening offset to one side of the 2032-mm side

■ An elevator car with minimum clear interior dimensions of 2032 mm (80 in.) by 1295 mm (51 in.), with a 915-mm (36-in.) clear door opening on the 1295-mm side of the car

Accessible Egress

In the National Building Code of Canada, every accessible floor above or below the ground entrance level that is not sprinklered throughout must include at least one of the following provisions for the temporary refuge or rescue of occupants requiring assistance.

Elevator service meeting the requirements for firefighter use may be provided. Elevator entrances must be protected by 1-hour or 45-minute rated vestibules or corridors separating the entrances from surrounding floor areas. If the building is four or more stories in height, the elevator hoistway must be provided with smoke protection as well.

Such floors may be divided into at least two separate areas of refuge by 1-hour or 45-minute rated fire separation walls. Travel distance from any point on the floor to a doorway leading to a separate refuge area may not exceed the limits in the table on page 312. The minimum size of such areas should be based on the number of occupants served, calculated according to the guidelines provided on page 283.

In Residential Occupancies, exterior balconies serving each suite or floor area may be provided. Such balconies must not be less than 1.5 m (59 in.) in depth, and must provide not less than 1.5 m^2 (16.1 sq ft) of area for each nonambulatory occupant, and 0.5 m^2 (5.4 sq ft) for each ambulatory occupant.

If site grading permits, this requirement may also be met by providing an exterior exit at ground level or a ramp leading to ground level.

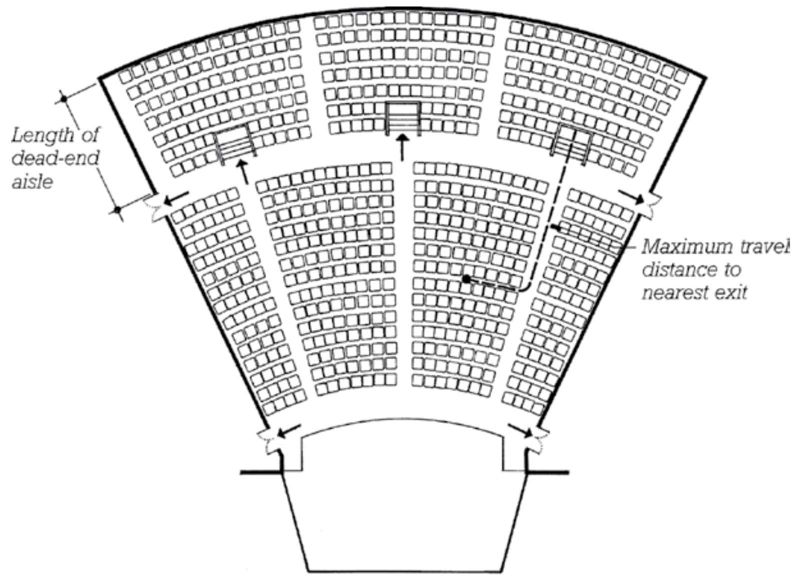
EGRESS FROM AUDITORIUMS, CONCERT HALLS, AND THEATERS

Assembly spaces, with their intense concentration of occupants, require special egress provisions to protect life safety. Auditorium fixed seating can take one of two approaches: In *conventional seating*, closely spaced seating rows are intersected by broader aisles, and occupants are conducted to relatively few exits. In *continental seating*, longer rows of seating without intermediate aisles are spaced slightly farther apart, and more exits are provided.

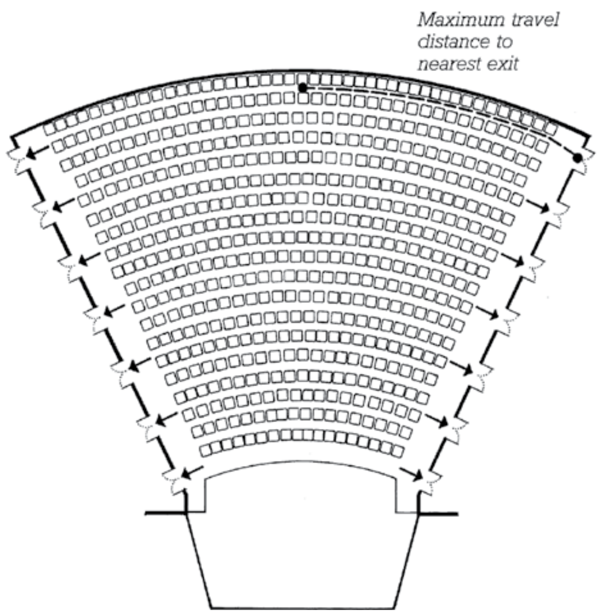
Today, both model codes accommodate both seating styles, but using one consolidated set of requirements for row length, row spacing, aisle widths, and travel distance. See the table on the following pages. In the table, *clear row spacing* refers to the clear space between the front edge of one row's seat cushion and the back of the next row. Where seats are self-rising, this measurement may be made with the seat in the raised position. See the illustration on this page.

In the International Building Code, Assembly spaces designed with special smoke control provisions are permitted reductions in width of seating rows and aisles, and increases in travel distances, particularly for spaces with larger occupant loads. Consult the code for details.

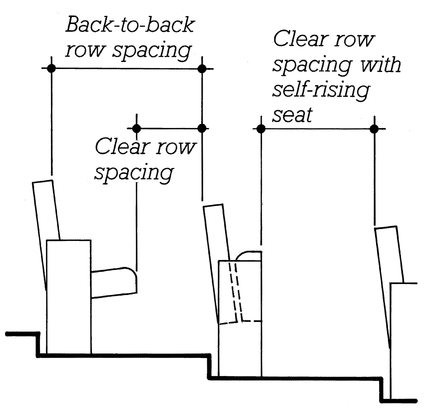
In the International Building Code, where Assembly spaces serve more than 300 occupants (including A Occupancies and accessory Assembly spaces in E Occupancies), the main exit of the building must provide egress capacity for at least half of the Assembly occupant load. Each Assembly space level having an occupant load greater than 300 must also provide access to both the main exit and alternative exits, each with an aggregate capacity equal to at least one-half the required exit capacity for that level. For A Occupancies, the main exit must front a public way. When Assembly spaces are designed without a defined main exit, multiple exits must be distributed around the perimeter of the building. Interior balconies, galleries, and press boxes with occupant loads of 50 or more must also be provided with two remote means of egress.



CONVENTIONAL ASSEMBLY SEATING



CONTINENTAL ASSEMBLY SEATING



ROW SPACING

	Seating	Aisles without Steps
International Building Code	For a row with egress at both ends: Maximum row length: 100 seats Minimum clear row spacing: 12″ (305 mm) plus 0.3″ (7.6 mm) for each additional seat above 14 For a row with egress at one end only: Maximum length: Limited by common path of egress travel Minimum clear row spacing: 12″ (305 mm) plus 0.6″ (15.2 mm) for each additional seat above 7 For both of the above, maximum clear row spacing is 22″ (559 mm). Where an egress path crosses an aisle and passes through another row of seats, that row may have up to 24 seats. Minimum row spacing is calculated as above, for a row with egress at one end only.	Aisle width: Minimum: 30″ (762 mm) for aisles serving not more than 14 seats; 36″ (914 mm) for aisles serving seating on one side, or not more than 50 seats on two sides; otherwise 42″ (1067 mm) For occupant load: Not less than 0.2″ (5.1 mm) per person for aisles sloped not more than 1:12, or 0.22″ (5.6 mm) per person for aisles with greater slopes Aisles providing egress at only one end may vary in width; aisles with egress at both ends must be uniform in width. Longest dead-end aisle: 20′ (6 m); longer dead ends are permitted where a second egress path is provided through a row of not more than 24 seats Aisle termination: Cross-aisles sized the same as above, considering combined capacity of all converging aisles Maximum aisle slope: 1:8
National Building Code of Canada	Continental seating: Maximum row length: 100 seats, with exit doorways provided at the end of each row, each doorway serving not more than three rows Minimum clear row spacing: 400 mm (15.8″) Conventional seating: Maximum row length: 7 seats with backs, or 20 seats without backs between any seat and an aisle Minimum clear row spacing: 400 mm (15.8”)	Aisle width: Minimum: 750 mm (29.5″) when serving not more than 60 seats; 900 mm (35.4″) when serving seats on only one side of the aisle; 1100 mm (43.3″) when serving 60 or more seats on two sides Increase the minimum aisle widths stated above in the direction of egress travel by 25 mm (1″) for each meter of length from the aisle's most remote point. Aisles providing egress at only one end may vary in width; aisles with egress at both ends must be uniform in width. Longest dead-end aisle: 6 m (19′-8″) Aisle termination: At cross-aisles, foyers, or exits with a width equal to the width of the widest aisle served, plus 50% of the width of the remaining aisles served Maximum aisle slope: 1:8

Stepped Aisles and Handrails	Egress Travel Limits (pp. 271–272)
Minimum tread depth: 11″ (279 mm) Maximum riser height: 8″ (203 mm); up to 9″ (229 mm) permitted where necessitated by slope of adjacent seating Minimum riser height: 4″ (102 mm) Minimum stair width: 36″ (914 mm) for stairs serving seating on one side, or not more than 50 seats on two sides, otherwise 48″ (1219 mm) Stair width for occupant load: Not less than 0.3″ (7.6 mm) per person for stairs with risers not greater than 7″ (178 mm) and treads not less than 11″ (279 mm); add an additional 0.005″ (0.13 mm) per person for each additional 0.1″ (2.5 mm) of riser height; where egress requires stair descent and no handrail is within 30" (762 mm) to either side, add an additional 0.075″ (1.9 mm) per person. Handrails required: All stairs and ramped aisles sloped more than 1:15 Handrails subdividing stairs or aisles serving seats on both sides may be discontinuous to allow aisle access; the minimum space between the handrail and adjacent seating is 23″ (574 mm).	Maximum travel distance to an exit: Unsprinklered: 200′ (61 m) Sprinklered: 250′ (76 m) In open-air seating: 400′ (122 m) to the exterior, or unlimited in Type I or II Construction Maximum common path of egress travel: Areas serving not more than 50 occupants: 75′ (23 m) Other areas: 30′ (9 m)
Minimum tread depth: 230 mm (9.1″) Minimum tread width: 250 mm (9.8″) Maximum riser height: 200 mm (7.9″) Minimum riser height: 110 mm (4.3″) Handrails: No special requirements	Maximum travel distance to an exit: Unsprinklered and sprinklered: 45 m (148′)

WHEELCHAIR SEATING CAPACITY

In Assembly spaces, minimum accommodations for wheelchair seating must be provided according to the adjacent table.

The International Building Code requires that wheelchair spaces within luxury suites or boxes be allocated within individual suites, and across all suites, according to the same rates. For example, a luxury box with 4 seats requires at least one wheelchair space, a box with 40 seats requires two such spaces, and 10 boxes of 3 seats each (30 seats total) require at least two wheelchair spaces among them.

Code	Total Capacity	Wheelchair Seating
International Building Code	4–25	1
	26–50	2
	51–100	4
	101–300	5
	301–500	6
	501–5000	6, plus 1 additional for each 150 seats or portion thereof
	5001 and over	36, plus 1 additional for each 200 seats or portion thereof
National Building Code of Canada	2–100	2
	101–200	3
	201–300	4
	301–400	5
	401–500	6
	501–900	7
	901–1300	8
	1301–1700	9
	1701 and over	9, plus 1 additional for each 400 seats or portion thereof

SIZE AND ARRANGEMENT OF WHEELCHAIR SEATING PLACES

The International Building Code requires wheelchair spaces to be at least 36 in. (914 mm) wide for single-chair spaces, and at least 33 in. (838 mm) wide each for multiple adjacent spaces. At least one fixed seat for a companion must be provided beside each required wheelchair space. Wheelchair spaces must be an integral part of the space seating plan. They must be separated into not less than the number of distinct locations indicated in the adjacent table, and these locations must be dispersed to provide a variety of viewing angles and distances, and offer access to varying amenities. In multilevel facilities, wheelchair seating must be provided on the main level and at least every other additional level. When a second floor or mezzanine provides no more than 25% of the total seating and not more than 300 seats total, all wheelchair spaces may be located on the main level. In the case of places of worship, this second-level 25% exception is the same, except that the total number of seats can exceed 300.

The National Building Code of Canada requires wheelchair spaces to be at least 900 mm (35.4 in.) wide, and if entered from the front or rear, at least 1220 mm (48 in.) deep, or if entered from the side, at least 1525 mm (60 in.) deep. Wheelchair spaces should be arranged so that at least two such spaces are located side by side. They should not infringe on any other egress path or width requirements, and they should be distributed so as to provide a choice of viewing location and a clear view of the event taking place.

Code	Total Capacity	Minimum Number of Separate Wheelchair Locations
International Building code	Up to 150	1
	151–150	2
	501–1000	3
	1001–5000	3, plus 1 additional for each 1000 seats or portion thereof
	5001 and over	7, plus 1 additional for each 2000 seats or portion thereof

INTERNATIONAL BUILDING CODE

Emergency Exterior Door or Window Egress

In all R-3 and R-4 Occupancies and any R-2 Occupancies with only one exit off a floor, most basements and all sleeping rooms on any level below the fourth story must have an exterior door or window opening for emergency escape and rescue that opens to a public way, a yard or court that leads to a public way, or an exit balcony that leads to a public way. All such openings must have a sill height of not more than 44 in. (1118 mm), minimum clear dimensions of 24 in. (610 mm) high by 20 in. (508 mm) wide, and a minimum opening area of at least 5.7 sq ft (0.53 m^2). For openings at the grade floor, the minimum open area is 5 sq ft (0.46 m^2).

Emergency escape windows or doors are not required for:

- Basements with a ceiling height of less than 80 in. (2030 mm), or with no habitable space and less than 200 sq ft (18.6m^2) in area
- Buildings over 75 ft (23 m) tall conforming to the code requirements for high-rise buildings (see the following section)

High-Rise Buildings

High-rise buildings are defined as those with occupied floors more than 75 ft (23 m) above the lowest level from which firefighters can deploy ground-based firefighting equipment, excluding open parking garages, airport traffic control towers, outdoor sports arenas, and some low- and medium-hazard industrial tall buildings. Special egress requirements for high-rise buildings include the following:

Exit Separation: Entrances to at least two exit stairways must be separated by a straight line measurement of not less than 30 ft (9.1 m) or one-fourth the largest diagonal measurement of the floor area served, whichever is less.

Number of Exits: Where the highest roof of a building with other than R-2 Occupancy is more than 420 ft (128 m) above grade, the number of required exits increases by one from the quantities described on page 277 (three exits for fewer than 500 occupants, four exits for fewer than 1000 occupants, etc.). Exit capacity must also be increased and balanced among the exits such that the loss of any single exit does not reduce the remaining exit capacity to less than that required for the occupant load of the area served. This extra stairway is not required where an elevator specially designed for occupant self-evacuation is provided (see Occupant Evacuation Elevators, in this list).

Smokeproof Exit Enclosures: Exit stairs must be protected by smokeproof enclosures, as described on page 281.

Emergency Escape and Rescue Openings: Emergency escape openings, as described earlier on this page, are not required (for bedrooms at any level or for basements).

Fire Service Access Elevator: In buildings with occupied floors higher than 120 ft (37 m) above lowest grade, one or more elevators designed to provide fire service access must serve every floor in the building. In buildings with just one elevator, one fire service access elevator is required. In buildings with two or more elevators, at least two such elevators must be provided. Fire service access elevators must travel within enclosed fire-resistance rated hoistway shafts and open to enclosed lobbies at each floor. These lobbies must have a minimum area of 150 sq ft (14 m^2), a minimum dimension of 8 ft (2.4 m), not less than a 1-hour fire-resistance rating, and direct access to an enclosed exit stair. Fire service lobbies do not need to be enclosed at the ground-floor level. Special elevator power, control, and monitoring systems are required. Fire service access elevators can function as conventional passenger or freight elevators during normal building operation.

Occupant Evacuation Elevators: Elevators specially designed for occupant self-evacuation during emergencies are also permitted, although not required. When used, such elevators can take the place of the required additional exit stairway previously described in Number of Exits. Requirements for occupant evacuation elevators are similar to those for fire service access elevators. Elevator lobbies must be sized as follows:

- At least 25% of the floor occupant load must be accommodated, at the rate of 3 sq ft (0.28 m^2) per person.
- One wheelchair space per 50 occupants (or portion thereof) must be provided.

One elevator can serve for both fire service access and occupant evacuation.

Underground Buildings

Underground buildings are defined as those with occupied floors more than 30 ft (9 m) below grade, excluding fully sprinklered enclosed garages, stadiums, arenas, and similar facilities; fixed guideway transit systems; fully sprinklered one- and two-family dwellings; and buildings in which only the lowest story is more than 30 ft (9 m) below grade, and that story is no more than 1500 sq ft (139 m^2) in area, with an occupant load of less than 10. Special egress requirements for underground buildings include the following:

Number of Exits: At least two exits are required from every floor.

Smokeproof Exit Enclosures: Exit stairs must be protected by smokeproof enclosures, as described on page 281.

Smoke Compartmentation: Buildings with floors more than 60 ft (18 m) below grade must have each floor, up to the highest level of exit discharge, divided into at least two compartments, with direct access to at least one exit in each compartment, and a 1-hour separation between compartments. Where elevators are provided, each compartment must have direct access to an elevator. Or, where one elevator serves multiple compartments, a lobby with a 1-hour separation from each compartment must be provided.

NATIONAL BUILDING CODE OF CANADA

Small Buildings

The National Building Code of Canada includes distinct requirements for *Housing and Small Buildings*, that is, buildings not greater than 600 m^2 (6458 sq ft) in horizontal extent, not greater than three stories in height, and serving only C Residential, D Business and Personal Services, E Mercantile, and F-2 or F-3 Medium- or Low-Hazard Industrial Occupancies. Some of the significant differences in requirements for buildings of this type are as follows. See the code for more details:

- Apartment buildings without elevators need only provide accessible access to the entrance level of the building. Where the difference in elevation between the entrance level and all dwelling units exceeds 600 mm (24 in.), no accessible access need be provided.
- Minimum width for public egress doorways is 800 mm (31 in.).
- Minimum width for public corridors is 900 mm (35 in.).
- Minimum width for public stairways is 900 mm (35 in.) and not less than 8 mm (0.3 in.) per occupant served; for stairways serving single living units, the minimum width is 860 mm (34 in.).
- Dimensional limits for stairway treads and risers are relaxed. See page 318.
- Emergency egress from bedrooms is required. See the following section.

Emergency Bedroom Door or Window Egress

In small buildings, as explained previously, dwelling units and other residential suites that are not sprinklered must have a window or door that opens directly to the exterior. Such openings must be operable from the inside without the need of keys, special tools, or special knowledge. Windows must not require the removal of sashes or hardware. The unobstructed opening area must not be less than 0.35 m^2 (3.8 sq ft), with a least dimension of 380 mm (15 in.) in either height or width.

Firefighter Ingress

On unsprinklered floors less than 25 m (82 ft) above grade, firefighter access must be provided by at least one unobstructed window or access panel, with minimum dimensions of 1100 mm (43 in.) high by 550 mm (22 in.) wide, with a sill height not greater than 900 mm (35 in.). At least one such opening must be provided for each 15 m (49 ft) of wall facing the street. Access panels above the first floor must allow operation from both the inside and outside, or must be glazed with plain glass.

Unsprinklered basements greater than 25 m (82 ft) in any horizontal dimension must provide firefighter access in the form of an exit stair connected directly to the outdoors, or a window or access panel as noted.

In buildings more than three stories in height with a roof slope less than 1:4, rooftop access must be provided from the floor immediately below, either by a stairway or by a fixed ladder and roof hatch.

High Buildings

The National Building Code of Canada defines *high buildings* as any of the following:

- Buildings containing A Assembly, D Business and Personal Services, E Mercantile, or F Industrial Occupancies, with a story greater than 36 m (118 ft) above grade
- Buildings containing the same Occupancies as above, with a story greater than 18 m (59 ft) above grade where the cumulative occupant load on or above any story above the grade-level story, divided by 1.8, exceeds 300 times the width in meters of all exit stairs serving that story
- Buildings with B Care or Detention Occupancies on a story greater than 18 m (59 ft) above grade
- Buildings with B-2 or B-3 Medical Treatment or Care Occupancies on the fourth or higher story
- Buildings with C Residential Occupancies on a story more than 18 m (59 ft) above grade

Firefighter Access Elevator: In high buildings, at least one elevator must be provided for firefighter access. This elevator must be located within 15 m (49 ft) of firefighter access to the building, have a usable platform area of not less than 2.2 m^2 (24 sq ft), and be protected by an unoccupied ¾-hour vestibule or an unoccupied 1-hour corridor enclosure at each floor. Elevator access must be provided to all floors above grade, by a single elevator, or with not more than one change of elevators.

Smoke Control: Special systems are required in high buildings to prevent the spread of smoke between floors, within exit stair enclosures, and between connected buildings.

Stairway enclosures must be provided with smoke control systems such as those described for smokeproof exit stair enclosures on page 281. Additionally, exit stairways must be designed to limit the possibility of smoke from fire on floors below the exit level contaminating stairway enclosures above the exit level. For example, stairway shafts serving floors above and below the exit level must be entirely separated or provided with separations within the shaft.

Elevator shafts serving floors above and below the lowest level of exit discharge must similarly be either entirely separate or, at each floor below the lowest level of exit discharge, a vestibule must separate the elevator from surrounding corridors and spaces.

Connected buildings must be designed to limit the passage of contaminated air between buildings, for example, with fire walls between the buildings and ventilated vestibules to limit the passage of smoke through openings in such walls.

2
SIZING THE EGRESS SYSTEM

This chapter presents simplified data for use in sizing egress components according to the requirements of the model building codes.

HOW TO SIZE THE EGRESS SYSTEM

The various parts of a building's egress system must be sized to accommodate the number of occupants and types of activities within the building so that, in the event of an emergency, occupants can safely and in a timely manner exit the building or move to protected areas. The information you need to complete the design of your building's egress system can be found in the tables and charts beginning on page 305 for the International Building Code and page 311 for the National Building Code of Canada. The following text explains how to apply this information to your project.

DETERMINING OCCUPANT LOADS

Begin with the Occupant Loads table on either page 305 or page 311, depending on your model code, to determine the number of occupants the various parts of your egress system must serve. For each distinct activity within your building, find the most closely matching use listed in the table and then read the floor area per occupant, or *occupant density*, for that use. Divide the area in your building associated with the activity by the occupant density to determine the number of occupants, or *occupant load*, for that area.

In both model codes, the occupant load for any space is determined by the larger of two calculations: either the number of persons dictated by the tabulated occupant densities, as explained in the previous paragraph, or the actual number of persons for whom the space is intended. For example, consider an open office space 3000 sq ft in area with workstations planned for 35 workers. According to the International Building Code (page 305), the prescribed occupant density for a business use is 100 sq ft per person, and the minimum occupant load for this space is therefore 30. However, since the workstations within the space have been designed to accommodate 35 persons, this second, larger number should be used for determining the capacity of the egress from this area.

Spaces are not always designed for a single purpose. Where a space is intended for more than one activity, the greatest occupant load determined for any of the activities should be used as the basis for sizing the egress system. Where a space designed for one activity could possibly be changed to some other use in the future, one that generates a higher occupant load, it may be appropriate to design the current egress system for such a future use, since enlarging egress system components at a later date is unlikely to be easily accomplished.

Within any floor of a building, occupant loads are cumulative. For example, in a room with a single doorway leading to a corridor, the doorway must be sized to accommodate the number of occupants in that room. However, where one room discharges into a second room that then opens to a corridor, the door opening to the corridor must be sized to accommodate the combined occupant load of both rooms. Likewise, corridors must be sized to accommodate the number of occupants from all spaces that discharge through them. Also, doorways into exit stairways and the stairways themselves must each be sized to accommodate their apportioned share of all the occupants of a floor.

Occupant loads from multiple floors are normally not cumulative. Thus, within an exit stairway, the width of the stairway and its discharge to the exterior are sized for the number of occupants from the single largest floor served, but not for the total number of occupants on all floors served by the stair. However, where egress paths from floors above and below converge at an intermediate level within a stairway or passageway, the egress width from that point on must be based on the sum of the converging occupant loads. Mezzanine occupants are also normally treated in this manner. That is, where a mezzanine discharges through the floor below, egress components serving that floor are sized for the combined occupant load of the floor and the mezzanine.

In the National Building Code of Canada, when theater or assembly hall occupant loads converge from interconnected floor spaces or multiple theater balconies, either exit stairs must be sized to accommodate the combined occupant loads or a protected floor area must be provided where occupants can safely queue while waiting to enter the exit.

EGRESS SYSTEM CRITERIA ACCORDING TO OCCUPANCY GROUP

The next step in sizing the egress system is to refer to the Occupancy Criteria table on either page 306 or page 312. For each building Occupancy classification, information such as maximum travel distance, minimum width of corridors and stairs, permitted length of dead-end corridors, and other requirements can be found. (If you have not already done so, turn to pages 6–17 to determine the Occupancy Groups for your building.) If your building is single-occupancy, the requirements for that Occupancy apply throughout. If your building is mixed-occupancy, the requirements for each Occupancy should be applied to the portion of the building serving that Occupancy. Where criteria in this table vary with the number of occupants served, use the occupant loads you calculated in the previous step to determine the appropriate requirements.

EGRESS COMPONENT CAPACITY

As the final step, calculations are performed to check the width of each door, corridor, ramp, stairway, and other components of the egress system to ensure that each has sufficient capacity for the number of occupants served. Required widths based on occupant load are determined using the Egress Component Capacity table (page 308 or page 314). For example, in the International Building Code, the minimum clear width for a doorway providing egress for 188 occupants in a sprinklered business use area would be calculated as follows:

> 188 persons × 0.20 in. per person = 37.6 in., rounded up to 38 in.

Taking into account the geometry of an opened door and its frame, not less than a nominal 40-in. wide doorway should be provided. Similar calculations should be performed for each component in the egress system. As a shortcut to performing these calculations, the Egress Width Calculator charts, on page 309 or page 315, can be used to determine these numbers graphically.

Note that egress components must meet the requirements of both tables, Occupancy Criteria and Egress Component Capacity. For example, consider a doorway serving a business use area, this time serving an occupant load of 150. According to the Egress Component Capacity table, a minimum clear width of 30 in. is required (150 × 0.20″ = 30″). However, since the Occupancy Criteria table lists a minimum doorway width of 32 in., this larger figure must be used. Further examples of calculating required widths of egress components using either model code are included on pages 308 and 314.

In determining the widths of egress components, the following must also be considered: Means of egress capacity may not diminish in the direction of egress travel. For example, an exit stairway providing egress for 50 occupants may not lead to an exit passageway with a capacity of only 40 occupants. Likewise, a stairway providing an egress capacity of 50 persons exiting from the fourth floor of a building must maintain at least that capacity all the way to the ground-level exit discharge, even if lower floors require a capacity of only 40 persons each.

Where a space or floor requires more than one independent means of egress, the required egress capacity is distributed among the various egress ways provided. In such cases, the capacity of the egress ways should be balanced such that the loss of any single one will not render the remaining capacity less than half of the total required. For example, consider an assembly hall with an occupant load of 600 persons and three means of egress, where the main entrance provides a capacity of 400 persons and the two remaining exits provide a capacity of 100 persons each. Even though a total egress capacity of 600 has been provided, elimination of the main entrance would leave a remaining capacity of only 200 persons. Since 200 is less than half of 600, this arrangement is not permitted. One solution to this problem would be to increase the size of just one of the smaller exits to a capacity of 200 persons. In this way, the elimination of any single exit still preserves an egress capacity of 300 or more.

In the table on the facing page, gross area includes all floor area inside of exterior walls, excluding only interior vent shafts and courts. Net area is intended to include only the actual occupied floor area and should exclude, for example, shafts, fixed equipment, corridors, stairways, toilet rooms, service rooms, closets, and the plan area occupied by all walls and partitions.

INTERNATIONAL BUILDING CODE

OCCUPANT LOADS

Use or Activity	Floor Area per Occupant
Agricultural buildings	300 ft^2 (28 m^2) gross
Aircraft hangars	500 ft^2 (46 m^2) gross
Airport terminal baggage claim	20 ft^2 (1.86 m^2) gross
Airport terminal baggage handling	300 ft^2 (28 m^2) gross
Airport terminal waiting areas	15 ft^2 (1.4 m^2) gross
Assembly Occupancy, concentrated seating (chairs only, not fixed)	7 ft^2 (0.65 m^2) net
Assembly Occupancy, gaming floors	11 ft^2 (1.0 m^2) gross
Assembly Occupancy, standing space	5 ft^2 (0.46 m^2) net
Assembly Occupancy, unconcentrated seating (tables, chairs, stages, platforms)	15 ft^2 (1.4 m^2) net For booth seating without dividing arms, use an 18-in. (457-mm) width per occupant.
Bowling centers	5 occupants per lane plus 7 ft^2 (0.65 m^2) net for other areas
Business areas	150 ft^2 (14 m^2) gross
Business areas, concentrated use	50 ft^2 (4.65 m^2) net
Courtrooms, other than fixed seating	40 ft^2 (3.7 m^2) net
Day care areas	35 ft^2 (3.3 m^2) net
Educational Occupancy, classroom areas	20 ft^2 (1.86 m^2) net
Educational Occupancy, shops and vocational areas	50 ft^2 (4.65 m^2) net
Exercise areas	50 ft^2 (4.65 m^2) gross
Factories, industrial areas	100 ft^2 (9.3 m^2) gross
Hazardous Occupancies: Groups H-1, H-2, H-3, H-4	100 ft^2 (9.3 m^2) gross
Hazardous Occupancies: Group H-5	200 ft^2 (18.6 m^2) gross
Institutional Occupancy, inpatient treatment areas	240 ft^2 (22.3 m^2) gross
Institutional Occupancy, outpatient treatment areas	100 ft^2 (9.3 m^2) gross
Institutional Occupancy, sleeping areas	120 ft^2 (11.2 m^2) gross
Kitchens, commercial	200 ft^2 (18.6 m^2) gross
Libraries, reading rooms	50 ft^2 (4.65 m^2) net
Libraries, stack areas	100 ft^2 (9.3 m^2) gross
Locker rooms	50 ft^2 (4.65 m^2) gross
Mechanical equipment rooms	300 ft^2 (28 m^2) gross
Mercantile Occupancy	60 ft^2 (5.6 m^2) gross
Mercantile Occupancy, enclosed shopping malls	30 to 50 ft^2 (2.8–4.65 m^2) gross; see the code
Museums, galleries	30 ft^2 (2.8 m^2)
Parking garages	200 ft^2 (19 m^2) gross
Residential Occupancy, dormitories	50 ft^2 (4.65 m^2) gross
Residential Occupancy, general	200 ft^2 (19 m^2) gross
Skating rinks and swimming pools, rink and pool area	50 ft^2 (4.65 m^2) gross
Skating rinks and swimming pools, decks	15 ft^2 (1.4 m^2) gross
Stages and platforms	15 ft^2 (1.4 m^2) net
Storage, stock, and shipping areas	300 ft^2 (28 m^2) gross
Warehouses	500 ft^2 (46 m^2) gross

OCCUPANCY CRITERIA

Occupancy (pp. 6–12)	Maximum Travel Distance (pp. 271–272)		Maximum Common Path of Egress Travel (p. 272)	Largest Area with Single Exit (p. 270)
	Unsprinklered	Sprinklered		
A: Assembly	200′ (61 m) 400′ (122 m) for open-air seating with combustible construction or unlimited distance with noncombustible construction	250′ (76 m)	30′ (9 m) for assembly fixed seating with 50 or more occupants 75′ (23 m) for others	49 occupants
B: Business	200′ (61 m)	300′ (91 m)	75′ (23 m) unsprinklered 100′ (30 m) sprinklered or for unsprinklered areas with an occupant load of 30 or less	49 occupants
E: Educational	200′ (61 m)	250′ (76 m)	75′ (23 m)	49 occupants
F-1: Factory, Moderate Hazard	200′ (61 m)	250′ (76 m)	75′ (23 m) 100′ (30 m) sprinklered	49 occupants
F-2: Factory, Low Hazard	300′ (91 m)	400′ (122 m)	Same as above	49 occupants
H-1, H-2, H-3: Hazardous	Not permitted	H-1: 75′ (23 m) H-2: 100′ (30 m) H-3: 150′ (46 m)	25′ (8 m)	3 occupants
H-4, H-5: Hazardous	Not permitted	H-4: 175′ (53 m) H-5: 200′ (61 m)	75′ (23 m)	10 occupants
I-1: Institutional, Residential Care	Not permitted	250′ (76 m)	75′ (23 m)	10 occupants
I-2: Institutional, Custodial Care	Not permitted	200′ (61 m)	50′ (15 m) within any sleeping room 100′ (30 m) within care suites	1000 ft² (93 m²) for care suites with sleeping rooms; 2500 ft² (232 m²) for other care suites
I-3 Institutional, Detention and Security	Not permitted	200′ (61 m)	100′ (30 m)	10 occupants
I-4: Institutional, Day Care	150′ (46 m)	200′ (61 m)	75′ (23 m)	10 occupants
M: Mercantile	200′ (61 m)	250′ (76 m)	75′ (23 m)	49 occupants
M: Mercantile, Covered malls	Not permitted	200′ (61 m)	75′ (23 m)	49 occupants
R-1: Hotels and Motels	Not permitted	250′ (76 m)	75′ (23 m)	10 occupants
R-2: Residential, Multifamily	Not permitted	250′ (76 m)	125′ (38 m)	20 occupants
R-3: Residential, One- and Two-Family, except below	Not permitted	250′ (76 m) 200′ (61 m) with NFPA 13D sprinkler system	125′ (38 m)	20 occupants
Detached, three-story maximum, one- and two-family dwellings and townhouses	Not applicable	Not applicable	Not applicable	Not applicable
R-4: Residential, Assisted Living	Not permitted	250′ (76 m)	125′ (38 m)	20 occupants
S-1: Storage, Moderate Hazard	200′ (61 m)	250′ (76 m)	75′ (23 m) unsprinklered 100′ (30 m) sprinklered or for unsprinklered areas with an occupant load of 30 or less	29 occupants
S-2: Storage, Low Hazard, and Parking Garages	300′ (91 m)	400′ (122 m)	Same as above	29 occupants
U: Utility, and Private Garages	300′ (91 m)	400′ (122 m)	75′ (23 m) 100′ (30 m) for areas with an occupant load of 30 or less	49 occupants

	For minimum widths based on occupant load, see pages 305–309. For minimum dimensions of accessible routes, see pages 286–289.			
Minimum Length of Dead-End Corridor (p. 273)	**Minimum Door Width (p. 275)**	**Minimum Corridor Width**	**Minimum Stair Width**	**Other Requirements**
Greater of 20′ (6 m) or 2.5 × width of corridor	Min: 32″ (813 mm) net clear	44″ (1118 mm) serving more than 49 occupants 36″ (914 mm) serving 49 or fewer	44″ (1118 mm) serving more than 49 occupants 36″ (914 mm) serving 49 or fewer	For egress requirements in assembly seating areas, see pages 293–295.
Greater of 20′ (6 m) unsprinklered, 50′ (15 m) sprinklered, or 2.5 × width of corridor	Same as above	Same as above	Same as above	
Same as above	Same as above	Same as above, except 72″ (1829 mm) for 100 or more occupants	Same as above	
Same as above	Same as above	44″ (1118 mm) serving more than 49 occupants 36″ (914 mm) serving 49 or fewer	Same as above	
Same as above	Same as above	Same as above	Same as above	
Greater of 20′ (6 m) or 2.5 × width of corridor	Same as above	Same as above	Same as above	Consult the code for special requirements.
Same as above	Same as above	Same as above	Same as above	Consult the code for special requirements.
Greater of 20′ (6 m) sprinklered (NFPA 13R), 50′ (15 m) sprinklered (NFPA 13), or 2.5 × width of corridor	Min: 32″ (813 mm) net clear, not including interior sleeping unit doors	Same as above, except 72″ (1829 mm) where corridors server stretcher traffic	Same as above	For required emergency egress from sleeping areas, see page 297.
Greater of 20′ (6 m), 2.5 × width of corridor, or 30′ (9 m) in some conditions	Min: 32″ (813 mm) net clear; 41.5″ (1054 mm) where beds must be moved	Same as I-1 above, except 96″ (2438 mm) where beds must be moved	Same as above	Each floor must be subdivided by at least one smokeproof wall with horizontal exits. Exits from rooms or suites must lead directly to a corridor or the exterior.
Greater of 20′ (6 m) or 2.5 × width of corridor, or 50′ (15 m) in some conditions	Min: 32″ (813 mm) net clear; 28" (711 mm) for resident sleeping rooms	44″ (1118 mm) serving more than 49 occupants 36″ (914 mm) serving 49 or fewer	Same as above	Each floor must be subdivided by at least one smokeproof wall with horizontal exits.
Greater of 20′ (6 m) or 2.5 × width of corridor	Min: 32″ (813mm) net clear	Same as above	Same as above	
Greater of 20′ (6 m) unsprinklered, 50′ (15 m) sprinklered, or 2.5 × width of corridor	Same as above	Same as above	Same as above	
Same as above	Same as above	20′ (6 m) for mall space 66″ (1676 mm) for corridors	Same as above	Consult the code for special egress requirements.
Greater of 20′ (6 m) sprinklered (NFPA 13R), 50′ (15 m) sprinklered (NFPA 13), or 2.5 × width of corridor	Same as above	44″ (1118 mm) serving more than 49 occupants 36″ (914 mm) serving 49 or fewer, or within dwelling units	Same as above	For required emergency egress from sleeping areas, see page 297.
Same as above	Min: 32″ (813 mm) net clear, not including interior dwelling unit doors	Same as above	Same as above	Same as above
Greater of 20′ (6 m) or 2.5 × width of corridor	Same as above	Same as above	Same as above	Same as above
Not applicable	Same as above	36″ (914 mm)	36″ (914 mm)	Same as above
Greater of 20′ (6 m) or 2.5 × width of corridor	Same as above	44″ (1118 mm) serving more than 49 occupants 36″ (914 mm) serving 49 or fewer, or within dwelling units	44″ (1118 mm) serving more than 49 occupants 36″ (914 mm) serving 49 or fewer	Same as above
Greater of 20′ (6 m) unsprinklered, 50′ (15 m) sprinklered, or 2.5 × width of corridor	Min: 32″ (813 mm) net clear	44″ (1118 mm) serving more than 49 occupants 36″ (914 mm) serving 49 or fewer	Same as above	
Same as above	Same as above	Same as above	Same as above	Open parking garage exit stairways may be unenclosed.
Same as above	Same as above	Same as above	Same as above	

DETERMINING WIDTHS OF EGRESS COMPONENTS

Use the following chart to determine the minimum required width for the various parts of an egress system based on the occupant load served.

An Example Egress System Sizing Exercise

The Problem: Design the egress system for a department store main floor, unsprinklered, dimensions 210 × 292 ft.

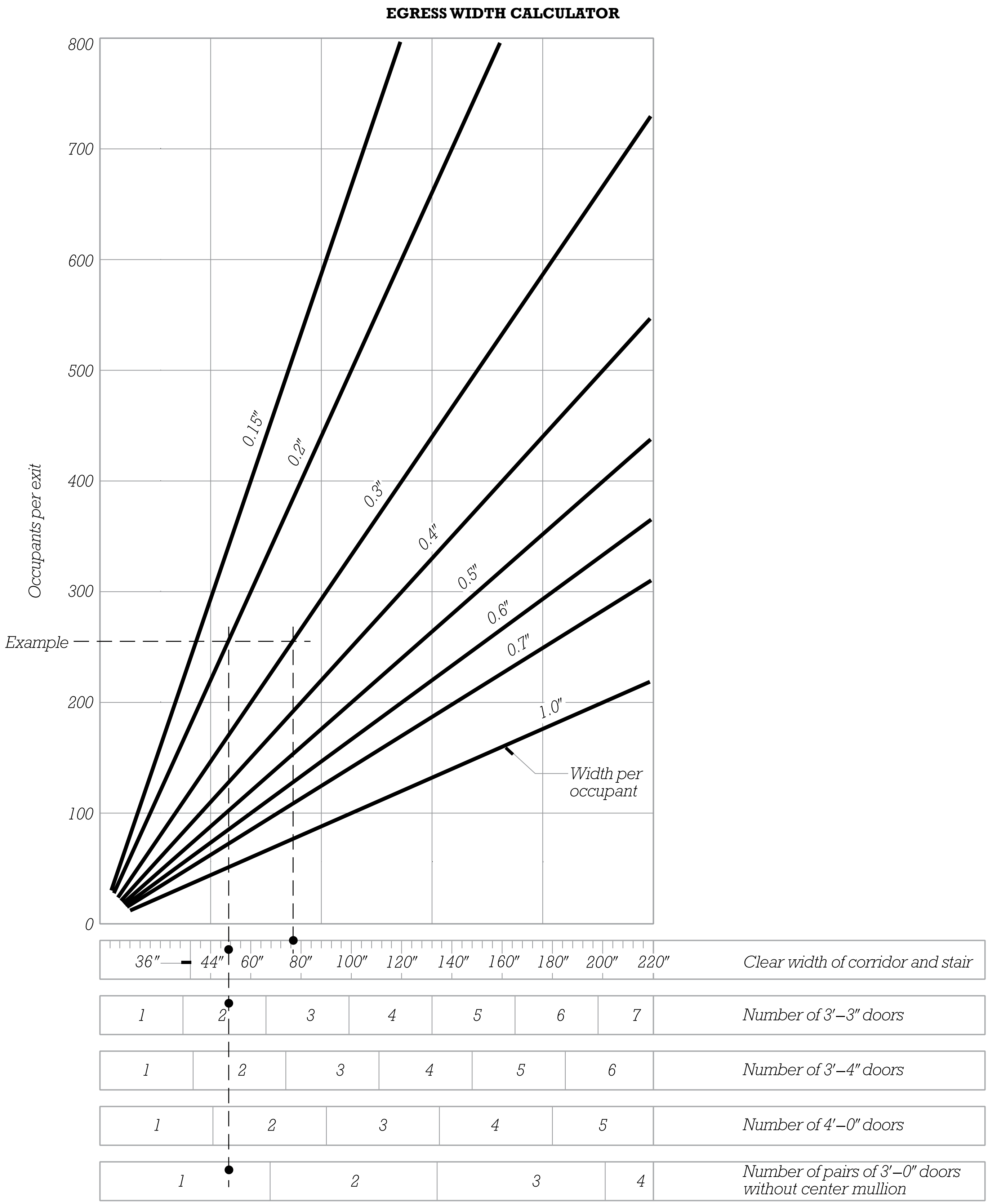
The Solution: From the index on page 9, we find that a department store is classified as an M Mercantile Occupancy. Multiplying the dimensions of the floor, we arrive at a gross area of 61,320 sq ft. From the Occupant Loads table on page 305, we see that for purposes of egress design, we must allocate at least 60 sq ft per occupant to arrive at an occupant load of 1022 persons for this floor. According to the information on page 277, a minimum of four exits is required. Assuming the occupant load is divided equally among the four, each exit must serve 256 persons.

From the Egress Component Capacity table on this page, we find that, because the building is unsprinklered, we must provide 0.20 in. of width per occupant in corridors and doorways and 0.30 in. per occupant in stairways. Moving to the chart on the facing page, we read horizontally from 256 occupants to the 0.20-in. line and then down to find that a width of 52 in. is required for the corridor. We compare this with the 44-in. minimum width indicated on page 307 and choose the larger of the two, 52 in. in this example. Extending this line farther downward, we select either two 3-ft doors or a pair of 3-ft doors without center mullion.

Reading horizontally from 256 occupants to the 0.3-in. line, then downward, we arrive at a required stair width of 77 in. (For stair design charts, see pages 321–331.)

EGRESS COMPONENT CAPACITY

Occupancy and Sprinklers	Width per Occupant	
	Doorways, Corridors, Ramps, and Other Components	**Stairs**
Fully sprinklered buildings with Occupancies other than H or I-2 (including NFPA 13 or 13R sprinklers)	0.15″ (3.8 mm)	0.2″ (5.1 mm)
All buildings not fully sprinklered throughout, and all H and I-2 occupancies	0.2″ (5.1 mm)	0.3″ (7.6 mm)


EGRESS WIDTH CALCULATOR
800
700
600
500
400
300
200
100
0
Occupants per exit
Example
0.15″
0.2″
0.3″
0.4″
0.5″
0.6″
0.7″
1.0″
Width per occupant
36″
44″
60″
80″
100″
120″
140″
160″
180″
200″
220″
Clear width of corridor and stair
1 2 3 4 5 6 7
Number of 3′–3″ doors
1 2 3 4 5 6
Number of 3′–4″ doors
1 2 3 4 5
Number of 4′–0″ doors
1 2 3 4
Number of pairs of 3′–0″ doors without center mullion

SIZING THE EGRESS SYSTEM

Instructions for using the charts on this and the following pages begin on page 303.

OCCUPANT LOADS

Occupancy	Use	Floor Area per Occupant
A: Assembly	Space with fixed seats	Actual number of seats
	Space with nonfixed seats, performance stages	0.75 m^2 (8.1 ft^2)
	Space with nonfixed seats and tables	0.95 m^2 (10 ft^2)
	Standing space	0.40 m^2 (4.3 ft^2)
	Bowling alleys, pool and billiard rooms, school shops and vocational rooms	9.30 m^2 (100 ft^2)
	Classrooms, reading or writing rooms, lounges	1.85 m^2 (20 ft^2)
	Dining, beverage, and cafeteria spaces	1.20 m^2 (13 ft^2)
	Laboratories in schools	4.60 m^2 (50 ft^2)
	Stadiums and grandstands	0.60 m^2 (6.5 ft^2)
B: Care, Treatment, and Detention	Suites	2 persons per sleeping room in suite
	Care, treatment, and sleeping areas	10.00 m^2 (107 ft^2)
	Detention quarters	11.60 m^2 (125 ft^2)
C: Residential	Dwelling units	2 persons per sleeping room
	Dormitories	4.60 m^2 (50 ft^2)
D: Business and Personal Services	Personal service shops	4.60 m^2 (50 ft^2)
	Offices	9.30 m^2 (100 ft^2)
E: Mercantile	Basements, first stories, second stories having a principal entrance from a pedestrian thoroughfare or a parking area	3.70 m^2 (40 ft^2)
	Other stories	5.60 m^2 (60 ft^2)
F: Industrial	Manufacturing or process rooms	4.60 m^2 (50 ft^2)
	Storage garages (parking), aircraft hangars	46.00 m^2 (495 ft^2)
	Storage spaces (warehouses)	28.00 m^2 (300 ft^2)
Other	Cleaning and repair goods	4.60 m^2 (50 ft^2)
	Kitchens	9.30 m^2 (100 ft^2)
	Public corridors intended for occupancy in addition to circulation	3.70 m^2 (40 ft^2)

OCCUPANCY CRITERIA

Occupancy	Maximum Travel Distance (See also pages 271–272)		Limits on Room or Suite That May Have Only One Exit Access	
	Unsprinklered	Sprinklered	Unsprinklered	Sprinklered
A-1: Assembly, Theaters	Not permitted	45 m (148 ft)	Not permitted	Occupancy: 60 Travel distance in room: 25 m (82 ft) Area: 200 m² (2153 ft²)
A-2: Assembly, Miscellaneous	30 m (98 ft)	45 m (148 ft)	Occupant load: 60 Travel distance in room: 15 m (49 ft) Area: 150 m² (1615 ft²)	Same as above
A-3: Assembly, Arenas	30 m (98 ft)	45 m (148 ft)	Same as above	Same as above
A-4: Assembly, Open Air	45 m (148 ft) to the ground, an exit, an opening leading from the seating area, or an opening through the seating deck structure	Not applicable	Same as above	Same as above
B-1: Detention	Not permitted	45 m (148 ft)	Not permitted	Same as above, except area: 100 m² (1076 ft²)
B-2: Medical Treatment	Not permitted	45 m (148 ft)	Not permitted	Same as above, except area: 100 m² (1076 ft²) sleeping rooms, 200 m² (2153 ft²) other areas
B-3: Care	Not permitted	45 m (148 ft)	Not permitted	Same as above, except area: 100 m² (1076 ft²) sleeping rooms, 150 m² (1615 ft²) sleeping suites, 200 m² (2153 ft²) other areas
C: Residential	30 m (98 ft)	45 m (148 ft)	Occupant load: 60 Travel distance in room: 15 m (49 ft) Area: 100 m² (1076 ft²)	Same as above, except area: 150 m² (1615 ft²)
D: Business and Personal Services	40 m (131 ft)	45 m (148 ft)	Occupant load: 60 Travel distance in room: 25 m (82 ft) Area: 200 m² (2153 ft²)	Same as above, except area: 300 m² (3229 ft²) area
E: Mercantile	30 m (98 ft)	45 m (148 ft)	Occupant load: 60 Travel distance in room: 15 m (49 ft)Area: 150 m² (1615 ft²)	Same as above, except area: 200 m² (2153 ft²)
F-1: Industrial, High-Hazard	25 m (82 ft)	25 m (82 ft)	Occupant load: 60 Area: 15 m² (161 ft²)	Occupancy: 60 Area: 15 m² (161 ft²)
F-2: Industrial, Medium-Hazard	30 m (98 ft)	45 m (148 ft)	Occupant load: 60 Travel distance in room: 10 m (33 ft) Area: 150 m² (1615 ft²)	Occupancy: 60 Travel distance in room: 25 m (82 ft)Area: 200 m² (2153 ft²)
F-3: Industrial, Low-Hazard	30 m (98 ft)	45 m (148 ft)	Occupant load: 60 Travel distance in room: 15 m (49 ft) Area: 200 m² (2153 ft²)	Same as above, except area: 300 m² (3229 ft²)
F-3: Open-Air Garages	60 m (197 ft)	60 m (197 ft)	Not applicable	Not applicable

Maximum Length of Dead-End Corridor (p. 273)	See also minimum width requirements for occupant load served on pages 304 and 311 and for accessible routes on pages 290–292.			
	Minimum Clear Corridor Width	Minimum Net Clear Egress Door Width	Minimum Stair Width	Additional Requirements
6 m (20 ft)	1100 mm (43 in.)	800 mm (31 in.)	900 mm (35 in.)[a] 1100 mm (43 in.)	See requirements for row spacing, aisles, and exits on pages 293–295.
6 m (20 ft)	1100 mm (43 in.)	800 mm (31 in.)	900 mm (35 in.)[a] 1100 mm (43 in.)	Same as above
6 m (20 ft)	1100 mm (43 in.)	800 mm (31 in.)	900 mm (35 in.)[a] 1100 mm (43 in.)	Same as above
6 m (20 ft)	1100 mm (43 in.)	800 mm (31 in.)	900 mm (35 in.)[a] 1100 mm (43 in.)	Maximum 25 m (82 ft) between exits. See the code for aisle and bleacher requirements.
None, except when the area served by the corridor has a separate independent means of egress	1100 mm (43 in.)	800 mm (31 in.)	900 mm (35 in.)[a] 1100 mm (43 in.)	
Same as above	1650 mm (65 in.) 2400 mm (94 in.) serving patients in beds 1100 mm (43 in.) for exit passageways	800 mm (31 in.) within suites 850 mm (33 in.) within public corridors and exits 1050 mm (41 in.) serving patients in beds	900 mm (35 in.)[a] 1100 mm (43 in.) 1650 mm (65 in.) serving residents from sleeping rooms	See page 283 for refuge area requirements.
Same as above, or 6 m (20 ft) when serving a residential suite	1100 mm (43 in.) serving not more than 10 residents 1650 mm (65 in.) 1100 mm (43 in.) for exit passageways	800 mm (31 in.) within suites 850 mm (33 in.) within public corridors and exits	900 mm (35 in.)[a] 1100 mm (43 in.) Serving 10 or more residents from sleeping rooms: 1100 mm (43 in.) [a] 1650 mm (65 in.)	Same as above
6 m (20 ft)	1100 mm (43 in.)	800 mm (31 in.)	900 mm (35 in.)[a] 1100 mm (43 in.)	
6 m (20 ft)	1100 mm (43 in.)	800 mm (31 in.)	900 mm (35 in.)[a] 1100 mm (43 in.)	
6 m (20 ft)	1100 mm (43 in.)	800 mm (31 in.)	900 mm (35 in.)[a] 1100 mm (43 in.)	
6 m (20 ft)	1100 mm (43 in.)	800 mm (31 in.)	900 mm (35 in.)[a] 1100 mm (43 in.)	
6 m (20 ft)	1100 mm (43 in.)	800 mm (31 in.)	900 mm (35 in.)[a] 1100 mm (43 in.)	
6 m (20 ft)	1100 mm (43 in.)	800 mm (31 in.)	900 mm (35 in.)[a] 1100 mm (43 in.)	
6 m (20 ft)	1100 mm (43 in.)	800 mm (31 in.)	900 mm (35 in.)[a] 1100 mm (43 in.)	

[a]Serving not more than two stories above or one story below the lowest exit level.

DETERMINING WIDTHS OF EGRESS COMPONENTS

Use the following chart to determine the minimum required width for the various parts of an egress system based on the occupant load served.

AN EXAMPLE EGRESS SYSTEM SIZING EXERCISE

The Problem: Design an exit for a department store basement, dimensions 33 × 85.2 m.

The Solution: From the index on page 15, we find that a department store is classified as an E Mercantile Occupancy. Multiplying the two dimensions of the floor, we arrive at a gross area of 2812 m^2. From the Occupant Loads table on page 311, we see that for purposes of egress design, we must allocate 3.7 m^2 per occupant to arrive at an occupant load of 760 persons for this floor. Assume that our design provides four exits. Dividing 760 occupants by four exits gives an occupant load per exit of 190.

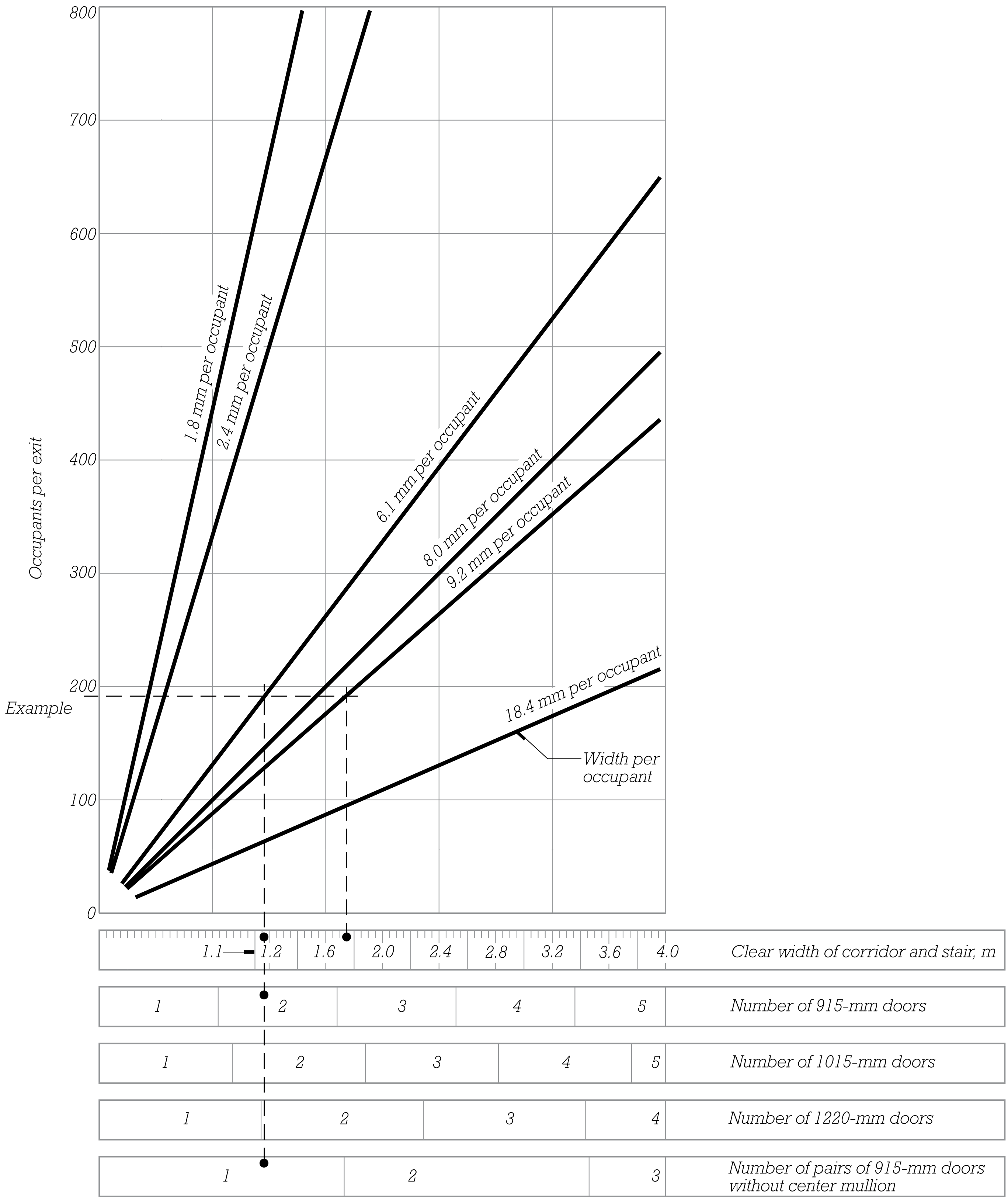
From the Egress Component Capacity table on this page, we find that for an E Occupancy, 6.1 mm of width per occupant is required for doors, corridors, and passageways. Moving to the chart on the facing page, we read horizontally from 190 occupants to the 6.1-mm line, then downward, to find that a corridor width of 1160 mm is required. Extending this line farther downward, we select either two 915-mm doors or one pair of 915-mm doors without a center mullion.

To find the required width for our egress stair, we read downward from the 9.2-mm line, finding that a width of 1750 mm is required for the steepest possible stair. (For stair design tables, see pages 321–331.)

EGRESS COMPONENT CAPACITY

Occupancy	Width per Occupant		
	Doors, Corridors, Ramps with Not More Than 1:8 Slope	**Stairs with Rise Not More Than 180 mm (7″) and Run Not Less Than 280 mm (11″)**	**Other Ramps and Stairs**
A-4: Open Air Assembly	2.4 mm (0.09″) for exit stairs 1.8 mm (0.07″) for aisles, ramps, passageways, exits, and stairs other than exit stairs		
B-2: Medical Treatment B-3: Care	18.4 mm (0.72″)	18.4 mm (0.72″)	18.4 mm (0.72″)
All other Occupancies	6.1 mm (0.24″)	8 mm (0.31″)	9.2 mm (0.36″)

EGRESS WIDTH CALCULATOR



3 STAIRWAY AND RAMP DESIGN

This chapter will help you design stairways and ramps in accordance with the model building codes.

STAIRS

In the following table, International Building Code *Residential Stairs* includes stairs in R-3 Occupancies, within dwelling units in R-2 Occupancies, and in U Occupancies accessory to R-3 Occupancies. In this code, changes in elevation of 12 inches (305 mm) or less within the means of egress must be accomplished with sloped surfaces or ramps, rather than stairs, whenever the route is required to be accessible.

National Building Code of Canada *Residential Stairs* includes stairs within dwelling units and exterior stairs serving individual dwelling units. This code requires interior egress stairs to have at least three risers, except within dwelling units or A-2 Occupancies used for serving food and beverages, when the stair is not less than 900 mm (35 in.) wide.

	Nonresidential Stairs			**Residential Stairs**			
Code	**Maximum Riser Height**	**Minimum Riser Height**	**Minimum Tread Run**	**Maximum Riser Height**	**Minimum Riser Height**	**Minimum Tread Depth**	**Maximum Vertical Distance between Landings**
International Building Code	7″ (178 mm)	4″ (102 mm)	11″ (279 mm) or 13″ (330 mm) for a stair with only one tread	7¾″ (197 mm)	None	10″ (254 mm)	12′ (3658 mm)
National Building Code of Canada	180 mm (7.1″)	125 mm (4.9″)	280 mm (11.0″)	200 mm (7.9″)	125 mm (4.9″)	255 mm (10.0″)	3.7 m (12′-2″) 2.4 m (7′-10″) in a B-2 Occupancy

RAMPS

Landings are required at the top and bottom of ramps, at regular intervals along ramps, and at doors opening onto ramps. In the International Building Code, landings must be at least as wide as the ramp, and on accessible routes, at least 60 in. (1525 mm) long. When not part of an accessible route, ramps may be 48 in. (1220 mm) long, or, if within nonaccessible R-2 or R-3 individual dwelling units, not less than 36 in. (9144 mm) long.

In the National Building Code of Canada, landings at the top and bottom of barrier-free ramps, as well as at intermediate locations leading to doors, must be 1500 mm (59 in.) square. Other intermediate landings must be at least as wide as the ramp, and not less than 1200 mm (47.25 in.) long.

RAMP PROPORTIONS

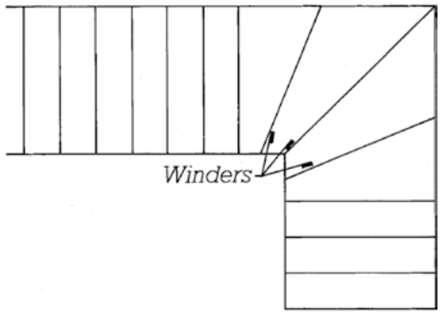
Code	**Maximum Slope**	**Minimum Width**	**Maximum Distance between Landings**
International Building Code	1:12 means of egress and accessible ramps 1:8 other ramps	36″ (914 mm) clear between sides of ramp or handrails, if any	30″ (762-mm) rise
National Building Code of Canada	1:12 barrier-free ramps 1:10 A, B, or C Occupancies 1:6 F Occupancies 1:8 other interior ramps 1:10 exterior ramps	870 mm (34″) between handrails of barrier-free ramps 1100-mm (43″) exit ramps 1650-mm (65″) exit ramps serving B-2 Occupancy sleeping rooms 860 mm (34″) serving dwelling units	9-m (29′-6″) run barrier-free ramps 1500-mm (59″) rise for other ramps

WINDING, CURVED, AND SPIRAL STAIRS

In the following tables, tread depth and riser height limits are the same as noted on the previous page for conventional stairs, unless indicated differently in the table. For nonrectangular treads, depth is measured along the *walk line*, 12 in. (305 mm) from the narrow end of the tread for the International Building Code, or 300 mm (11.8 in.) from the narrow end for the National Building Code of Canada. Where minimum depths are given for the narrow end of treads, depth requirements along the walk line still also apply.

WINDERS WITHIN STRAIGHT STAIRS

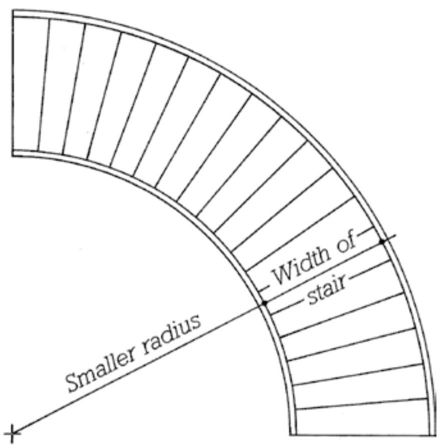
Code	Locations	Dimensional Restrictions
International Building Code	Permitted in egress stairs only within individual dwelling units, or in other stairs when not part of the required means of egress.	Nonresidential Stairs: Minimum tread depth 11″ (279 mm) at the walk line and 10″ (254 mm) at the narrow end. Residential stairs: 10″ (254 mm) at the walk line and 6″ (152 mm) at the narrow end.
National Building Code of Canada	Only in stairs within dwelling units.	One set of winders per floor level, arrayed at either 30° or 45°, up to 90° total. Winders may converge to a point.



WINDERS IN A STRAIGHT STAIR

CURVED AND CIRCULAR STAIRS

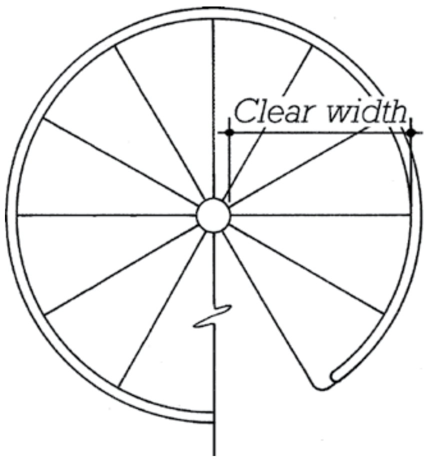
Code	Locations	Dimensional Restrictions
International Building Code	Any stair	Minimum tread depths same as Winders in Straight Stairs. See table above. Except within individual dwelling units, the smaller radius of the stair must be at least twice the required width of the stairway.
National Building Code of Canada	Any stair	Egress stairs: Minimum tread depth at the narrow end is 240 mm (9.4″). The smaller radius of the stair must be at least twice the width of the stairway. For stairs not part of the required means of egress: Minimum tread depth of 280 mm (11.0″) at the walk line and 150 mm (5.9″) at the narrow end.



CURVED STAIR

SPIRAL STAIRS

Code	Locations	Dimensional Restrictions
International Building Code	Permitted as egress stairs only within individual dwelling units, from a space not more than 250 ft^2 (23 m^2) in area serving not more than 5 occupants, or from technical production areas.	Minimum tread depth 6¾″ (171 mm) 12″ (305) from the narrow end Maximum riser height 9½″ (241 mm) Minimum clear width 26″ (660 mm) Minimum head room 78″ (1981 mm)
National Building Code of Canada	Permitted as part of the exit access, but not as an exit. When acting as the sole means of egress, may serve up to no more than × occupants.	Minimum tread depth 190 mm (7.5″) at walk line Maximum riser height 240 mm (9.4″) Minimum clear width 660 mm (26.0″) Minimum clear height 1980 mm (78.0″)



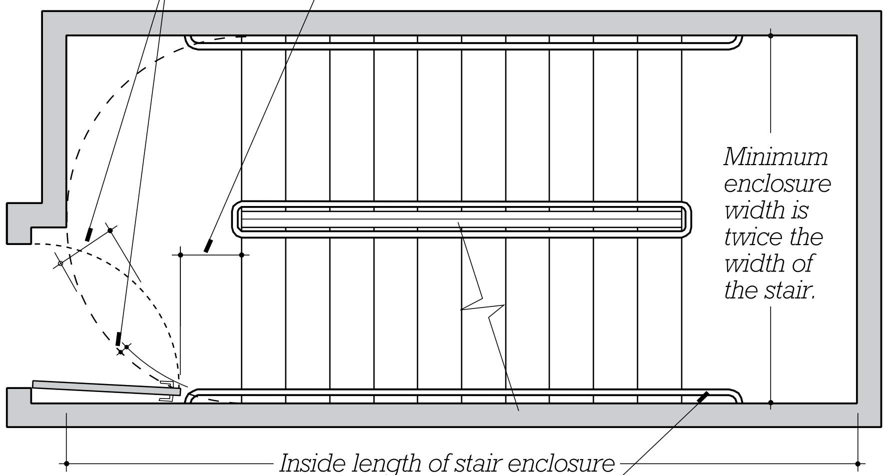
SPIRAL STAIR

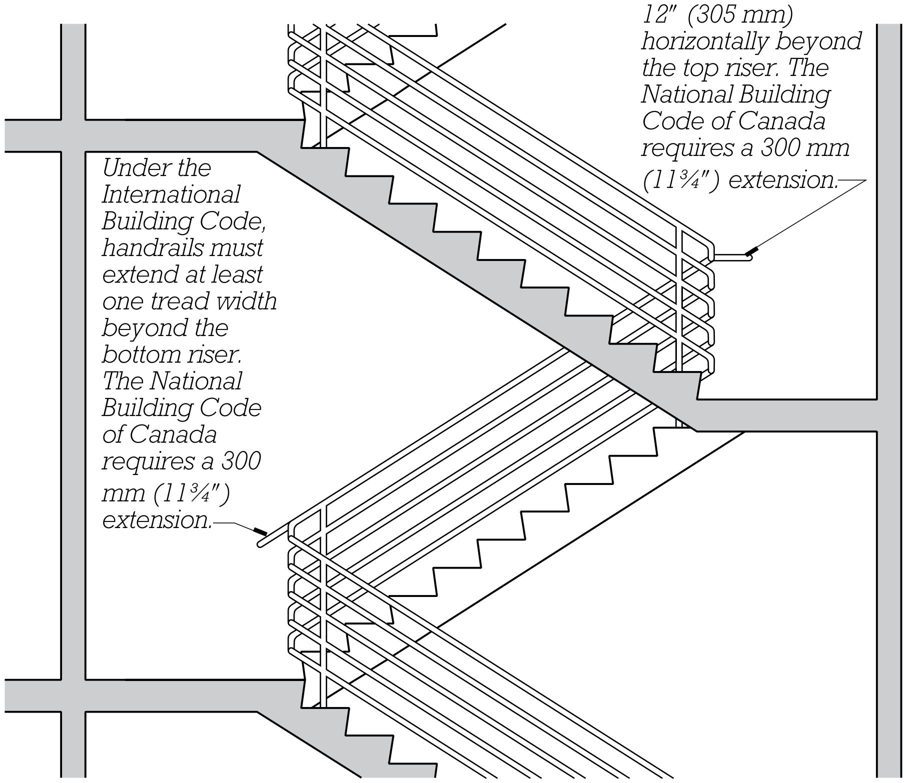
EXIT STAIRWAY DESIGN TABLES

The following tables allow you to rapidly complete a preliminary exit stairway design. After selecting the desired configuration, consult the accompanying table to find the required interior dimensions and the tread and riser proportions that correspond to the stair width and floor-to-floor height for which you are designing.

The stairway lengths for the English-unit tables are based on a maximum 7-in. (178-mm) riser and minimum 11-in. (279-mm) tread, conforming to the requirements of the International Building Code. Stairway lengths for the metric tables are based on a maximum 180-mm (7.1-in.) riser and minimum 280-mm (11-in.) tread, conforming to the requirements of the National Building Code of Canada. See page 318 for more information on stairway proportions.

In the tables, *Overall Inside Length of Stair Enclosure* represents a minimum configuration. Limits on door encroachment into the required egress width, both during the door's swing and when fully open, may dictate that the door be recessed into an alcove, or that the length of the stair enclosure be increased. The minimum width of any single flight of stairs is determined based on Occupancy and required egress capacity, as explained on pages 303–304. Under both model codes, this width is measured from the inside of the stairway or guards, not including handrails, which may project slightly further. (Or, for the minimum width of an accessible stair in the International Building Code, see pages 288–289.) To find the inside width of a complete stair enclosure, increase the required width of each flight by 2 to 6 inches (50 to 150 mm) to account for stair construction. For stairs with two flights side-by-side or for a doughnut stair, add × to 12 inches (100 to 300 mm) total, to account for the combined width of the multiple flights.





ONE-FLIGHT STAIR: ENGLISH UNITS

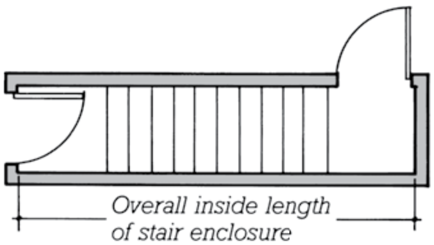
Floor-to-Floor Height (ft-in.)	Number of Risers	Riser Height (in.)	Tread Depth (in.)	Overall Inside Length of Stair Enclosure (ft-in.)				
				36″ Width	44″ Width	56″ Width	66″ Width	88″ Width
1-8	3	6.67	11	7-10	9-2	11-2	12-10	16-6
2-0	4	6.00	11	8-9	10-1	12-1	13-9	17-5
2-4	4	7.00	11	8-9	10-1	12-1	13-9	17-5
2-8	5	6.40	11	9-8	11-0	13-0	14-8	18-4
3-0	6	6.00	11	10-7	11-11	13-11	15-7	19-3
3-4	6	6.67	11	10-7	11-11	13-11	15-7	19-3
3-8	7	6.29	11	11-6	12-10	14-10	16-6	20-2
4-0	7	6.86	11	11-6	12-10	14-10	16-6	20-2
4-4	8	6.50	11	12-5	13-9	15-9	17-5	21-1
4-8	8	7.00	11	12-5	13-9	15-9	17-5	21-1
5-0	9	6.67	11	13-4	14-8	16-8	18-4	22-0
5-4	10	6.40	11	14-3	15-7	17-7	19-3	22-11
5-8	10	6.80	11	14-3	15-7	17-7	19-3	22-11
6-0	11	6.55	11	15-2	16-6	18-6	20-2	23-10
6-4	11	6.91	11	15-2	16-6	18-6	20-2	23-10
6-8	12	6.67	11	16-1	17-5	19-5	21-1	24-9
7-0	12	7.00	11	16-1	17-5	19-5	21-1	24-9
7-4	13	6.77	11	17-0	18-4	20-4	22-0	25-8
7-8	14	6.57	11	17-11	19-3	21-3	22-0	26-7
8-0	14	6.86	11	17-11	19-3	21-3	22-11	26-7
8-4	15	6.67	11	18-10	20-2	22-2	23-10	27-6
8-8	15	6.93	11	18-10	20-2	22-2	23-10	27-6
9-0	16	6.75	11	19-9	21-1	23-1	24-9	28-5
9-4	16	7.00	11	19-9	21-1	23-1	24-9	28-5
9-8	17	6.82	11	20-8	22-0	24-0	25-8	29-4
10-0	18	6.67	11	21-7	22-11	24-11	26-7	30-3
10-4	18	6.89	11	21-7	22-11	24-11	26-7	30-3
10-8	19	6.74	11	22-6	23-10	25-10	27-6	31-2
11-0	19	6.95	11	22-6	23-10	25-10	27-6	31-2
11-4	20	6.80	11	23-5	24-9	26-9	28-5	32-1
11-8	20	7.00	11	23-5	24-9	26-9	28-5	32-1
12-0	21	6.86	11	24-4	25-8	27-8	29-4	33-0

Stairway widths may be determined rapidly by using the tables and graphs on pages 308–309 and 314–315.

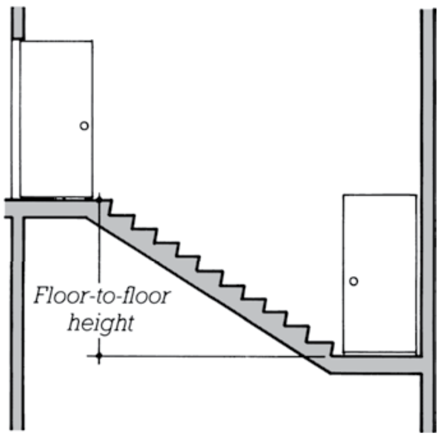
EXIT STAIRWAY DESIGN TABLES

ONE-FLIGHT STAIR: METRIC UNITS

Floor-to-Floor Height (m)	Number of Risers	Riser Height (mm)	Tread Depth (mm)	Overall Inside Length of Stair Enclosure (m)				
				900-mm Width	1100-mm Width	1400-mm Width	1650-mm Width	2200-mm Width
0.5	3	167	280	2.36	2.76	3.36	3.86	4.96
0.6	4	150	280	2.64	3.04	3.64	4.14	5.24
0.7	4	175	280	2.64	3.04	3.64	4.14	5.24
0.8	5	160	280	2.92	3.32	3.92	4.42	5.52
0.9	5	180	280	2.92	3.32	3.92	4.42	5.52
1.0	6	167	280	3.20	3.60	4.20	4.70	5.80
1.1	7	158	280	3.48	3.88	4.48	4.98	6.08
1.2	7	172	280	3.48	3.88	4.48	4.98	6.08
1.3	8	163	280	3.76	4.16	4.76	5.26	6.36
1.4	8	175	280	3.76	4.16	4.76	5.26	6.36
1.5	9	167	280	4.04	4.44	5.04	5.54	6.64
1.6	9	178	280	4.04	4.44	5.04	5.54	6.64
1.7	10	170	280	4.32	4.72	5.32	5.82	6.92
1.8	10	180	280	4.32	4.72	5.32	5.82	6.92
1.9	11	173	280	4.60	5.00	5.60	6.10	7.20
2.0	12	167	280	4.88	5.28	5.88	6.38	7.48
2.1	12	175	280	4.88	5.28	5.88	6.38	7.48
2.2	13	170	280	5.16	5.56	6.16	6.66	7.76
2.3	13	177	280	5.16	5.56	6.16	6.66	7.76
2.4	14	172	280	5.44	5.84	6.44	6.94	8.04
2.5	14	179	280	5.44	5.84	6.44	6.94	8.04
2.6	15	174	280	5.72	6.12	6.72	7.22	8.32
2.7	15	180	280	5.72	6.12	6.72	7.22	8.32
2.8	16	175	280	6.00	6.40	7.00	7.50	8.60
2.9	17	171	280	6.28	6.68	7.28	7.78	8.88
3.0	17	177	280	6.28	6.68	7.28	7.78	8.88
3.1	18	173	280	6.56	6.96	7.56	8.06	9.16
3.2	18	178	280	6.56	6.96	7.56	8.06	9.16
3.3	19	174	280	6.84	7.24	7.84	8.34	9.44
3.4	19	179	280	6.84	7.24	7.84	8.34	9.44
3.5	20	175	280	7.12	7.52	8.12	8.62	9.72
3.6	20	180	280	7.12	7.52	8.12	8.62	9.72
3.7	21	177	280	7.40	7.80	8.40	8.90	10.00



ONE-FLIGHT STAIR



TWO-FLIGHT STAIR: ENGLISH UNITS

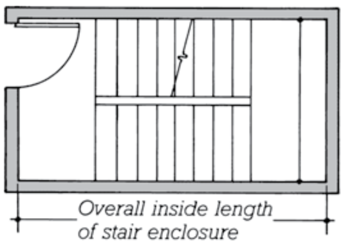
Floor-to-Floor Height (ft-in.)	Number of Risers	Riser Height (in.)	Tread Depth (in.)	Overall Inside Length of Stair Enclosure (ft-in.)				
				36″ Width	44″ Width	56″ Width	66″ Width	88″ Width
7-8[a]	14	6.57	11	11-6	12-10	14-10	16-6	20-2
8-0[a]	14	6.86	11	11-6	12-10	14-10	16-6	20-2
8-4	15	6.67	11	12-5	13-9	15-9	17-5	21-1
8-8	15	6.93	11	12-5	13-9	15-9	17-5	21-1
9-0	16	6.75	11	12-5	13-9	15-9	17-5	21-1
9-4	16	7.00	11	12-5	13-9	15-9	17-5	21-1
9-8	17	6.82	11	13-4	14-8	16-8	18-4	22-0
10-0	18	6.67	11	13-4	14-8	16-8	18-4	22-0
10-4	18	6.89	11	13-4	14-8	16-8	18-4	22-0
10-8	19	6.74	11	14-3	15-7	17-7	19-3	22-11
11-0	19	6.95	11	14-3	15-7	17-7	19-3	22-11
11-4	20	6.80	11	14-3	15-7	17-7	19-3	22-11
11-8	20	7.00	11	14-3	15-7	17-7	19-3	22-11
12-0	21	6.86	11	15-2	16-6	18-6	20-2	23-10
12-4	22	6.73	11	15-2	16-6	18-6	20-2	23-10
12-8	22	6.91	11	15-2	16-6	18-6	20-2	23-10
13-0	23	6.78	11	16-1	17-5	19-5	21-1	24-9
13-4	23	6.96	11	16-1	17-5	19-5	21-1	24-9
13-8	24	6.83	11	16-1	17-5	19-5	21-1	24-9
14-0	24	7.00	11	16-1	17-5	19-5	21-1	24-9
14-4	25	6.88	11	17-0	18-4	20-4	22-0	25-8
14-8	26	6.77	11	17-0	18-4	20-4	22-0	25-8
15-0	26	6.92	11	17-0	18-4	20-4	22-0	25-8
16-0	28	6.86	11	17-11	19-3	21-3	22-11	26-7
17-0	30	6.80	11	18-10	20-2	22-2	23-10	27-6
18-0	31	6.97	11	19-9	21-1	23-1	24-9	28-5
19-0	33	6.91	11	20-8	22-0	24-0	25-8	29-4
20-0	35	6.86	11	21-7	22-11	24-11	26-7	30-3
21-0	36	7.00	11	21-7	22-11	24-11	26-7	30-3
22-0	38	6.95	11	22-6	23-10	25-10	27-6	31-2
23-0	40	6.90	11	23-5	24-9	26-9	28-5	32-1
24-0	42	6.86	11	24-4	25-8	27-8	29-4	33-0

[a]The headroom in these stairs may be deficient, depending on the detailing of the stair structure.
Stairway widths may be determined rapidly by using the tables and graphs on pages 308–309 and 314–315.

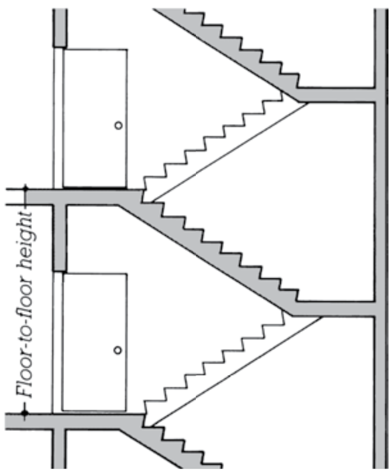
EXIT STAIRWAY DESIGN TABLES

TWO-FLIGHT STAIR: METRIC UNITS

Floor-to-Floor Height (m)	Number of Risers	Riser Height (mm)	Tread Depth (mm)	Overall Inside Length of Stair Enclosure (m)				
				900-mm Width	1100-mm Width	1400-mm Width	1650-mm Width	2200-mm Width
2.3	13	177	280	3.48	3.88	4.48	4.98	6.08
2.4	14	172	280	3.48	3.88	4.48	4.98	6.08
2.5	14	179	280	3.48	3.88	4.48	4.98	6.08
2.6	15	174	280	3.76	4.16	4.76	5.26	6.36
2.7	15	180	280	3.76	4.16	4.76	5.26	6.36
2.8	16	175	280	3.76	4.16	4.76	5.26	6.36
2.9	17	171	280	4.04	4.44	5.04	5.54	6.64
3.0	17	177	280	4.04	4.44	5.04	5.54	6.64
3.1	18	173	280	4.04	4.44	5.04	5.54	6.64
3.2	18	178	280	4.04	4.44	5.04	5.54	6.64
3.3	19	174	280	4.32	4.72	5.32	5.82	6.92
3.4	19	179	280	4.32	4.72	5.32	5.82	6.92
3.5	20	175	280	4.32	4.72	5.32	5.82	6.92
3.6	20	180	280	4.32	4.72	5.32	5.82	6.92
3.7	21	177	280	4.60	5.00	5.60	6.10	7.20
3.8	22	173	280	4.60	5.00	5.60	6.10	7.20
3.9	22	178	280	4.60	5.00	5.60	6.10	7.20
4.0	23	174	280	4.88	5.28	5.88	6.38	7.48
4.1	23	179	280	4.88	5.28	5.88	6.38	7.48
4.2	24	175	280	4.88	5.28	5.88	6.38	7.48
4.3	24	180	280	4.88	5.28	5.88	6.38	7.48
4.4	25	176	280	5.16	5.56	6.16	6.66	7.76
4.5	25	180	280	5.16	5.56	6.16	6.66	7.76
4.8	27	178	280	5.44	5.84	6.44	6.94	8.04
5.1	29	176	280	5.72	6.12	6.72	7.22	8.32
5.4	30	180	280	5.72	6.12	6.72	7.22	8.32
5.7	32	179	280	6.00	6.40	7.00	7.50	8.60
6.0	34	177	280	6.28	6.68	7.28	7.78	8.88
6.3	35	180	280	6.56	6.96	7.56	8.06	9.16
6.6	37	179	280	6.84	7.24	7.84	8.34	9.44
6.9	39	177	280	7.12	7.52	8.12	8.62	9.72
7.2	40	180	280	7.12	7.52	8.12	8.62	9.72
7.4	42	177	280	7.40	7.80	8.40	8.90	100



TWO-FLIGHT STAIR



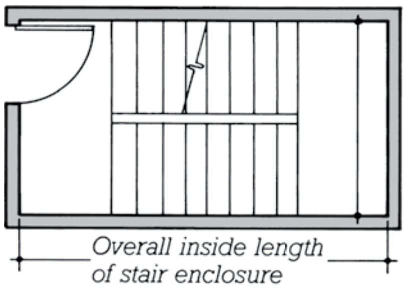
THREE-FLIGHT STAIR: ENGLISH UNITS

Floor-to-Floor Height (ft-in.)	Number of Risers	Riser Height (in.)	Tread Depth (in.)	Overall Inside Length of Stair Enclosure (ft-in.)				
				36″ Width	44″ Width	56″ Width	66″ Width	88″ Width
12-0	21	6.86	11	11-6	12-10	14-10	16-6	20-2
12-4	22	6.73	11	12-5	13-9	15-9	17-5	21-1
12-8	22	6.91	11	12-5	13-9	15-9	17-5	21-1
13-0	23	6.78	11	12-5	13-9	15-9	17-5	21-1
13-4	23	6.96	11	12-5	13-9	15-9	17-5	21-1
13-8	24	6.83	11	12-5	13-9	15-9	17-5	21-1
14-0	24	7.00	11	12-5	13-9	15-9	17-5	21-1
14-4	25	6.88	11	13-4	14-8	16-8	18-4	22-0
14-8	26	6.77	11	13-4	14-8	16-8	18-4	22-0
15-0	26	6.92	11	13-4	14-8	16-8	18-4	22-0
16-0	28	6.86	11	14-3	15-7	17-7	19-3	22-11
17-0	30	6.80	11	14-3	15-7	17-7	19-3	22-11
18-0	31	6.97	11	15-2	16-6	18-6	20-2	23-10
19-0	33	6.91	11	15-2	16-6	18-6	20-2	23-10
20-0	35	6.86	11	16-1	17-5	19-5	21-1	24-9
21-0	36	7.00	11	16-1	17-5	19-5	21-1	24-9
22-0	38	6.95	11	17-0	18-4	20-4	22-0	25-8
23-0	40	6.90	11	17-11	19-3	21-3	22-11	26-7
24-0	42	6.86	11	17-11	19-3	21-3	22-11	26-7

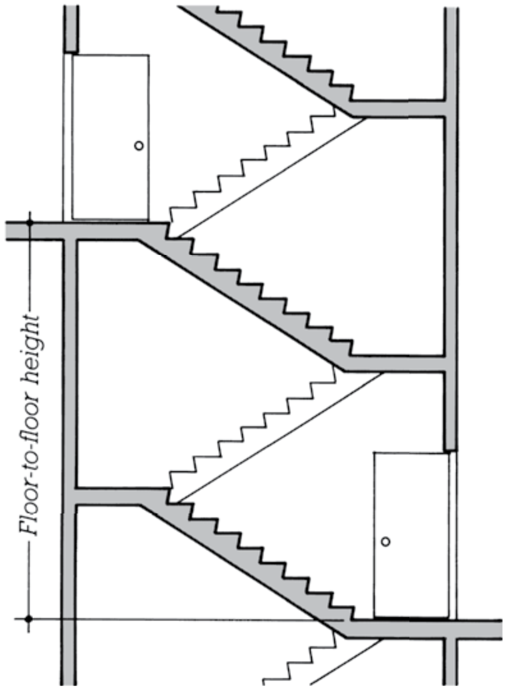
Stairway widths may be determined rapidly by using the tables and graphs on pages 308–309 and 314–315.

THREE-FLIGHT STAIR: METRIC UNITS

Floor-to-Floor Height (m)	Number of Risers	Riser Height (mm)	Tread Depth (mm)	Overall Inside Length of Stair Enclosure (m)				
				900-mm Width	1100-mm Width	1400-mm Width	1650-mm Width	2200-mm Width
3.6	20	180	280	3.48	3.88	4.48	4.98	6.08
3.7	21	177	280	3.48	3.88	4.48	4.98	6.08
3.8	22	173	280	3.76	4.16	4.76	5.26	6.36
3.9	22	178	280	3.76	4.16	4.76	5.26	6.36
4.0	23	174	280	3.76	4.16	4.76	5.26	6.36
4.1	23	179	280	3.76	4.16	4.76	5.26	6.36
4.2	24	175	280	3.76	4.16	4.76	5.26	6.36
4.3	24	180	280	3.76	4.16	4.76	5.26	6.36
4.4	25	176	280	4.04	4.44	5.04	5.54	6.64
4.5	25	180	280	4.04	4.44	5.04	5.54	6.64
4.8	27	178	280	4.04	4.44	5.04	5.54	6.64
5.1	29	176	280	4.32	4.72	5.32	5.82	6.92
5.4	30	180	280	4.32	4.72	5.32	5.82	6.92
5.7	32	179	280	4.60	5.00	5.60	6.10	7.20
6.0	34	177	280	4.88	5.28	5.88	6.38	7.48
6.3	35	180	280	4.88	5.28	5.88	6.38	7.48
6.6	37	179	280	5.16	5.56	6.16	6.66	7.76
6.9	39	177	280	5.16	5.56	6.16	6.66	7.76
7.2	40	180	280	5.44	5.84	6.44	6.94	8.04
7.4	42	177	280	5.44	5.84	6.44	6.94	8.04



THREE-FLIGHT STAIR



FOUR-FLIGHT STAIR: ENGLISH UNITS

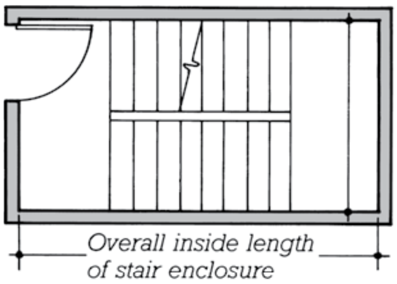
Floor-to-Floor Height (ft-in.)	Number of Risers	Riser Height (in.)	Tread Depth (in.)	Overall Inside Length of Stair Enclosure (ft-in.)				
				36″ Width	44″ Width	56″ Width	66″ Width	88″ Width
16-0	28	6.86	11	11-6	12-10	14-10	16-6	20-2
17-0	30	6.80	11	12-5	13-9	15-9	17-5	21-1
18-0	31	6.97	11	12-5	13-9	15-9	17-5	21-1
19-0	33	6.91	11	13-4	14-8	16-8	18-4	22-0
20-0	35	6.86	11	13-4	14-8	16-8	18-4	22-0
21-0	36	7.00	11	13-4	14-8	16-8	18-4	22-0
22-0	38	6.95	11	14-3	15-7	17-7	19-3	22-11
23-0	40	6.90	11	14-3	15-7	17-7	19-3	22-11
24-0	42	6.86	11	15-2	16-6	18-6	20-2	23-10

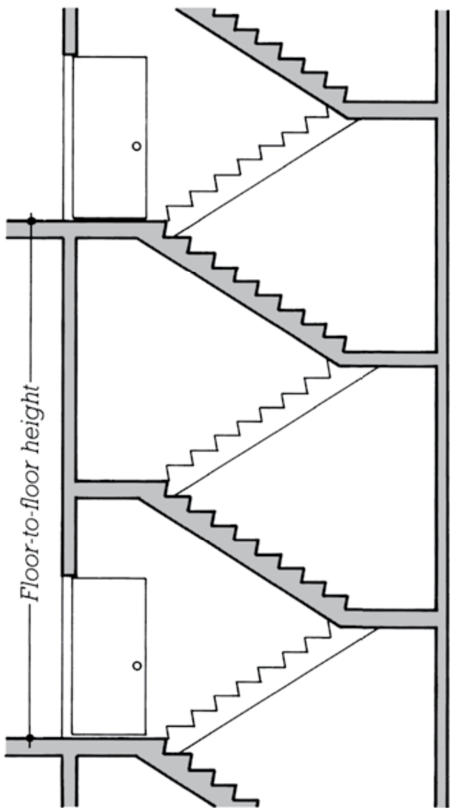
Stairway widths may be determined rapidly by using the tables and graphs on pages 308–309 and 314–315.

EXIT STAIRWAY DESIGN TABLES

FOUR-FLIGHT STAIR: METRIC UNITS

Floor-to-Floor Height (m)	Number of Risers	Riser Height (mm)	Tread Depth (mm)	Overall Inside Length of Stair Enclosure (m)				
				900-mm Width	1100-mm Width	1400-mm Width	1650-mm Width	2200-mm Width
4.8	27	178	280	3.48	3.88	4.48	4.98	6.08
5.1	29	176	280	3.76	4.16	4.76	5.26	6.36
5.4	30	180	280	3.76	4.16	4.76	5.26	6.36
5.7	32	179	280	3.76	4.16	4.76	5.26	6.36
6.0	34	177	280	4.04	4.44	5.04	5.54	6.64
6.3	35	180	280	4.04	4.44	5.04	5.54	6.64
6.6	37	179	280	4.32	4.72	5.32	5.82	6.92
6.9	39	177	280	4.32	4.72	5.32	5.82	6.92
7.2	40	180	280	4.32	4.72	5.32	5.82	6.92
7.4	42	177	280	4.60	5.00	5.60	6.10	7.20





FOUR-FLIGHT STAIR

DOUGHNUT STAIR: ENGLISH UNITS

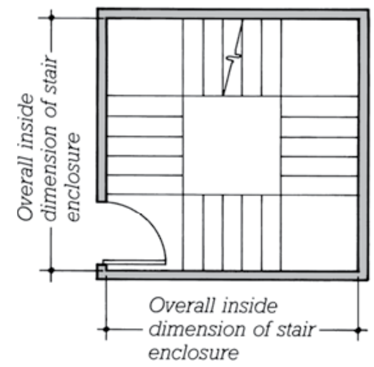
Floor-to-Floor Height (ft-in.)	Number of Risers	Riser Height (in.)	Tread Depth (in.)	Overall Inside Length of Stair Enclosure (ft-in.)				
				36″ Width	44″ Width	56″ Width	66″ Width	88″ Width
7-8	14	6.57	11	7-10 × 8-9	9-2 × 10-1	11-2 × 12-1	12-10 × 13-9	16-6 × 17-5
8-0	14	6.86	11	7-10 × 8-9	9-2 × 10-1	11-2 × 12-1	12-10 × 13-9	16-6 × 17-5
8-4	15	6.67	11	8-9 × 8-9	10-1 × 10-1	12-1 × 12-1	13-9 × 13-9	17-5 × 17-5
8-8	15	6.93	11	8-9 × 8-9	10-1 × 10-1	12-1 × 12-1	13-9 × 13-9	17-5 × 17-5
9-0	16	6.75	11	8-9 × 8-9	10-1 × 10-1	12-1 × 12-1	13-9 × 13-9	17-5 × 17-5
9-4	16	7.00	11	8-9 × 8-9	10-1 × 10-1	12-1 × 12-1	13-9 × 13-9	17-5 × 17-5
9-8	17	6.82	11	8-9 × 9-8	10-1 × 11-0	12-1 × 13-0	13-9 × 14-8	17-5 × 18-4
10-0	18	6.67	11	8-9 × 9-8	10-1 × 11-0	12-1 × 13-0	13-9 × 14-8	17-5 × 18-4
10-4	18	6.89	11	8-9 × 9-8	10-1 × 11-0	12-1 × 13-0	13-9 × 14-8	17-5 × 18-4
10-8	19	6.74	11	9-8 × 9-8	11-0 × 11-0	13-0 × 13-0	14-8 × 14-8	18-4 × 18-4
11-0	19	6.95	11	9-8 × 9-8	11-0 × 11-0	13-0 × 13-0	14-8 × 14-8	18-4 × 18-4
11-4	20	6.80	11	9-8 × 9-8	11-0 × 11-0	13-0 × 13-0	14-8 × 14-8	18-4 × 18-4
11-8	20	7.00	11	9-8 × 9-8	11-0 × 11-0	13-0 × 13-0	14-8 × 14-8	18-4 × 18-4
12-0	21	6.86	11	9-8 × 10-7	11-0 × 11-11	13-0 × 13-11	14-8 × 15-7	18-4 × 19-3
12-4	22	6.73	11	9-8 × 10-7	11-0 × 11-11	13-0 × 13-11	14-8 × 15-7	18-4 × 19-3
12-8	22	6.91	11	9-8 × 10-7	11-0 × 11-11	13-0 × 13-11	14-8 × 15-7	18-4 × 19-3
13-0	23	6.78	11	10-7 × 10-7	11-11 × 11-11	13-11 × 13-11	15-7 × 15-7	19-3 × 19-3
13-4	23	6.96	11	10-7 × 10-7	11-11 × 11-11	13-11 × 13-11	15-7 × 15-7	19-3 × 19-3
13-8	24	6.83	11	10-7 × 10-7	11-11 × 11-11	13-11 × 13-11	15-7 × 15-7	19-3 × 19-3
14-0	24	7.00	11	10-7 × 10-7	11-11 × 11-11	13-11 × 13-11	15-7 × 15-7	19-3 × 19-3
14-4	25	6.88	11	10-7 × 11-6	11-11 × 12-10	13-11 × 14-10	15-7 × 16-6	19-3 × 20-2
14-8	26	6.77	11	10-7 × 11-6	11-11 × 12-10	13-11 × 14-10	15-7 × 16-6	19-3 × 20-2
15-0	26	6.92	11	10-7 × 11-6	11-11 × 12-10	13-11 × 14-10	15-7 × 16-6	19-3 × 20-2
16-0	28	6.86	11	11-6 × 11-6	12-10 × 12-10	14-10 × 14-10	16-6 × 16-6	20-2 × 20-2
17-0	30	6.80	11	11-6 × 12-5	12-10 × 13-9	14-10 × 15-9	16-6 × 17-5	20-2 × 21-1
18-0	31	6.97	11	12-5 × 12-5	13-9 × 13-9	15-9 × 15-9	17-5 × 17-5	21-1 × 21-1
19-0	33	6.91	11	12-5 × 13-4	13-9 × 14-8	15-9 × 16-8	17-5 × 18-4	21-1 × 22-0
20-0	35	6.86	11	13-4 × 13-4	14-8 × 14-8	16-8 × 16-8	18-4 × 18-4	22-0 × 22-0
21-0	36	7.00	11	13-4 × 13-4	14-8 × 14-8	16-8 × 16-8	18-4 × 18-4	22-0 × 22-0
22-0	38	6.95	11	13-4 × 14-3	14-8 × 15-7	16-8 × 17-7	18-4 × 19-3	22-0 × 22-11
23-0	40	6.90	11	14-3 × 14-3	15-7 × 15-7	17-7 × 17-7	19-3 × 19-3	22-11 × 22-11
24-0	42	6.86	11	14-3 × 15-2	15-7 × 16-6	17-7 × 18-6	19-3 × 20-2	22-11 × 23-10

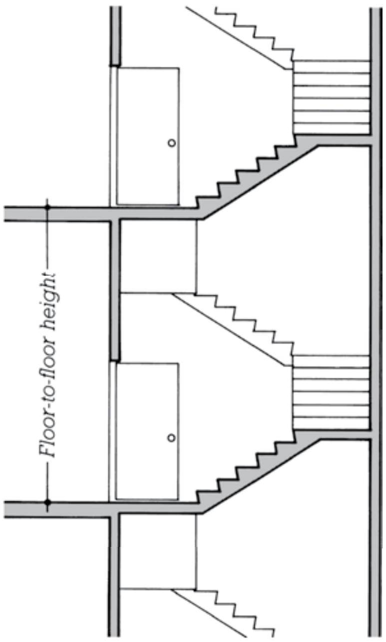
Stairway widths may be determined rapidly by using the tables and graphs on pages 308–309 and 314–315.

EXIT STAIRWAY DESIGN TABLES

DOUGHNUT STAIR: METRIC UNITS

Floor-to-Floor Height (m)	Number of Risers	Riser Height (mm)	Tread Depth (mm)	Overall Inside Length of Stair Enclosure (m)				
				900-mm Width	1100-mm Width	1400-mm Width	1650-mm Width	2200-mm Width
2.3	13	177	280	2.36 × 2.64	2.76 × 3.04	3.36 × 3.64	3.86 × 4.14	4.96 × 5.24
2.4	14	172	280	2.36 × 2.64	2.76 × 3.04	3.36 × 3.64	3.86 × 4.14	4.96 × 5.24
2.5	14	179	280	2.36 × 2.64	2.76 × 3.04	3.36 × 3.64	3.86 × 4.14	4.96 × 5.24
2.6	15	174	280	2.64 × 2.64	3.04 × 3.04	3.64 × 3.64	4.14 × 4.14	5.24 × 5.24
2.7	15	180	280	2.64 × 2.64	3.04 × 3.04	3.64 × 3.64	4.14 × 4.14	5.24 × 5.24
2.8	16	175	280	2.64 × 2.64	3.04 × 3.04	3.64 × 3.64	4.14 × 4.14	5.24 × 5.24
2.9	17	171	280	2.64 × 2.92	3.04 × 3.32	3.64 × 3.92	4.14 × 4.42	5.24 × 5.52
3.0	17	177	280	2.64 × 2.92	3.04 × 3.32	3.64 × 3.92	4.14 × 4.42	5.24 × 5.52
3.1	18	173	280	2.64 × 2.92	3.04 × 3.32	3.64 × 3.92	4.14 × 4.42	5.24 × 5.52
3.2	18	178	280	2.64 × 2.92	3.04 × 3.32	3.64 × 3.92	4.14 × 4.42	5.24 × 5.52
3.3	19	174	280	2.92 × 2.92	3.32 × 3.32	3.92 × 3.92	4.42 × 4.42	5.52 × 5.52
3.4	19	179	280	2.92 × 2.92	3.32 × 3.32	3.92 × 3.92	4.42 × 4.42	5.52 × 5.52
3.5	20	175	280	2.92 × 2.92	3.32 × 3.32	3.92 × 3.92	4.42 × 4.42	5.52 × 5.52
3.6	20	180	280	2.92 × 2.92	3.32 × 3.32	3.92 × 3.92	4.42 × 4.42	5.52 × 5.52
3.7	21	177	280	2.92 × 3.20	3.32 × 3.60	3.92 × 4.20	4.42 × 4.70	5.52 × 5.80
3.8	22	173	280	2.92 × 3.20	3.32 × 3.60	3.92 × 4.20	4.42 × 4.70	5.52 × 5.80
3.9	22	178	280	2.92 × 3.20	3.32 × 3.60	3.92 × 4.20	4.42 × 4.70	5.52 × 5.80
4.0	23	174	280	3.20 × 3.20	3.60 × 3.60	4.20 × 4.20	4.70 × 4.70	5.80 × 5.80
4.1	23	179	280	3.20 × 3.20	3.60 × 3.60	4.20 × 4.20	4.70 × 4.70	5.80 × 5.80
4.2	24	175	280	3.20 × 3.20	3.60 × 3.60	4.20 × 4.20	4.70 × 4.70	5.80 × 5.80
4.3	24	180	280	3.20 × 3.20	3.60 × 3.60	4.20 × 4.20	4.70 × 4.70	5.80 × 5.80
4.4	25	176	280	3.20 × 3.48	3.60 × 3.88	4.20 × 4.48	4.70 × 4.98	5.80 × 6.08
4.5	25	180	280	3.20 × 3.48	3.60 × 3.88	4.20 × 4.48	4.70 × 4.98	5.80 × 6.08
4.8	27	178	280	3.48 × 3.48	3.88 × 3.88	4.48 × 4.48	4.98 × 4.98	6.08 × 6.08
5.1	29	176	280	3.48 × 3.76	3.88 × 4.16	4.48 × 4.76	4.98 × 5.26	6.08 × 6.36
5.4	30	180	280	3.48 × 3.76	3.88 × 4.16	4.48 × 4.76	4.98 × 5.26	6.08 × 6.36
5.7	32	179	280	3.76 × 3.76	4.16 × 4.16	4.76 × 4.76	5.26 × 5.26	6.36 × 6.36
6.0	34	177	280	3.76 × 4.04	4.16 × 4.44	4.76 × 5.04	5.26 × 5.54	6.36 × 6.64
6.3	35	180	280	4.04 × 4.04	4.44 × 4.44	5.04 × 5.04	5.54 × 5.54	6.64 × 6.64
6.6	37	179	280	4.04 × 4.32	4.44 × 4.72	5.04 × 5.32	5.54 × 5.82	6.64 × 6.92
6.9	39	177	280	4.32 × 4.32	4.72 × 4.72	5.32 × 5.32	5.82 × 5.82	6.92 × 6.92
7.2	40	180	280	4.32 × 4.32	4.72 × 4.72	5.32 × 5.32	5.82 × 5.82	6.92 × 6.92
7.4	42	177	280	4.32 × 4.60	4.72 × 5.00	5.32 × 5.60	5.82 × 6.10	6.92 × 7.20





DOUGHNUT STAIR

SECTION

6

DESIGNING FOR PARKING

1 DESIGN CRITERIA FOR PARKING FACILITIES

This chapter will help you select an appropriate type of parking facility and establish criteria for its capacity, level of amenity, and accessibility. For facilities other than surface parking, it will also assist you in the selection and configuration of a structural system.

PARKING FACILITY TYPES

Surface parking is constructed solely at grade. It is the least expensive form of parking, requiring little more than site preparation, paving, storm drainage, and related improvements. Surface parking is the most land-use intensive of all parking types and is also the most common type, comprising more than two-thirds of all parking in the United States.

Structured parking is contained within enclosed or open buildings. In comparison to surface parking, structured parking consumes less land. However, the building structure adds costs. Structured parking is normally chosen where the high cost or limited availability of land makes surface parking uneconomical or impractical. Structured parking is also a better choice for very large parking facilities where the walking distance from parking stalls to the facility served would otherwise become too long.

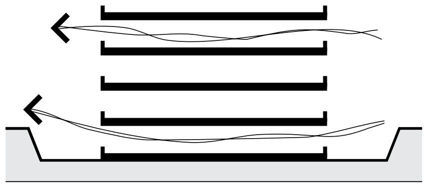
Structured parking can be open or enclosed. *Open parking* relies on natural ventilation to prevent the dangerous accumulation of toxic exhaust gases or flammable vapors within the structure.

Where natural ventilation is not a practical option, parking may be contained in mechanically ventilated structures called *enclosed parking*. Because of the added expense of the mechanical systems and a complete building enclosure, enclosed parking structures are more expensive than open ones. Enclosed parking may be constructed above or below grade. Above-grade structures are designed as enclosed rather than open when natural ventilation is not practical, such as where exterior walls abut other buildings or are too close to permit the extensive openings required for an open garage. Wherever parking is constructed substantially below grade, enclosed parking is the only choice, since natural ventilation is not feasible. Because of the significant added costs associated with excavation and other aspects of below-ground construction, enclosed below-grade parking is the most expensive form of conventional parking facility. On the other hand, from a resource conservation point of view, it may also consume the least land of any conventional type of parking facility.

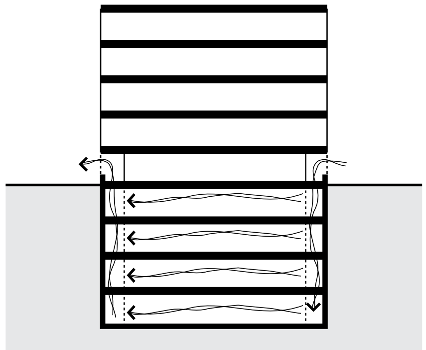
Automated parking is a specialized type of structured parking in which vehicles are transported within the facility on specially designed lifting and conveying equipment, rather than through a conventional system of drivable ramps and parking aisles. The additional expense of the conveying systems in these facilities is offset by their ability to store roughly twice as many vehicles as a conventional facility of equal size. Automated parking facilities may also offer advantages in improved car security, lower staffing costs, and more rapid vehicle delivery than provided by conventional facilities. They are most economically attractive in locations with very high land costs or on highly constrained sites. This chapter does not provide design guidelines for this type of facility; manufacturers of automated parking facility equipment should be consulted for more information.

Thus, listed in order from lowest to highest cost, the choice of parking facility type is typically as follows:

- Surface parking
- Open parking structure, above grade
- Enclosed parking structure, above grade
- Enclosed parking structure, below grade
- Automated parking facility



OPEN PARKING STRUCTURE WITH NATURAL VENTILATION



ENCLOSED BELOW-GRADE PARKING STRUCTURE WITH MECHANICAL VENTILATION

Parking facilities also have negative environmental and social impacts. They may consume land, generate harmful rainwater runoff, and contribute to urban heating. By supporting private automobile dependence, they also contribute to fossil fuel consumption, increases in traffic congestion, and the construction of roadways. These impacts can be mitigated by building less parking, by sharing parking among neighboring facilities with differing patterns of demand, by providing facilities to support carpooling, bicycling, and public transportation, and by choosing parking facility types and designs that minimize the consumption of open land. Surface parking in particular, because it requires the most land area, is generally the least environmentally friendly option. For more information on minimizing the impacts of surface parking, see pages 347–348.

PARKING CAPACITY

The planned capacity of a parking facility—that is, the number of parking stalls that will be provided—may be dictated by local land-use regulations or other ordinances, or it may be established on the basis of anticipated demand, reflecting the parking needs of the facilities to be served. Ordinances that dictate parking requirements are not addressed in this chapter, as they are unique to each locality. The designer should always seek out such information and verify the regulatory requirements for his or her project at the earliest possible stage of design.

Where parking capacity is based on estimates of demand, factors to be considered include the types of facilities being served, analyses of comparable sites, expected peak and average parking volumes, level of service expectations, anticipated patterns of use, the impact of nearby existing or planned parking facilities, area traffic studies, the availability of alternative transportation, and area economic and development projections. Since the combination of such factors is unique to any location, no one set of parking demand figures can be applied universally to all sites. However, where location-specific information is not available or has not yet been developed, the recommended parking ratios provided in the table on this page may be used for preliminary design purposes.

Type of Use Served by Parking	**Recommended Parking Ratios for Preliminary Design (1000 gross ft^2 = 93m^2 gross)**
Assembly Spaces such as theaters, arenas, cinemas, etc.	0.25 to 0.5 spaces per seat or occupant
Convenience Stores	2–10 per 1000 gross ft^2
Convention Centers	20 per 1000 gross ft^2
Hospitals and Medical Centers	The sum of: 0.1–0.75 per staff, plus 0.3–0.75 per bed, plus 0.2 per daily outpatient Or: 4–10 per 1000 gross ft^2
Hotels	The sum of: 0.2–1.5 spaces per room, plus 10–20 per 1000 gross ft^2 of public space and meeting rooms
Industrial Facilities	0.5–4 per 1000 gross ft^2
Office Buildings	0.5–6 per 1000 gross ft^2
Residential, Single-Family	1–2 spaces per dwelling unit
Residential, Multifamily	0.5–2 spaces per dwelling unit
Restaurants	10–20 per 1000 gross ft^2
Retail	2–4 per 1000 gross ft^2
Schools, K–12	The sum of: 1–1.5 per classroom, plus 0.25 per driving age student
Shopping Centers, Malls	2.5–15 per 1000 gross ft^2
Universities	The sum of: 0.1–0.5 spaces per student, and 0.8 spaces per staff

FACILITY LEVEL OF SERVICE

Parking facility design allows trade-offs between user convenience and comfort, on the one hand, and the economy and compactness of the facility, on the other. For example, the optimal size of a stall in a parking garage built in a dense urban setting, where space is at a premium and users are accustomed to constrained parking conditions, may be significantly smaller than that of a stall in a suburban shopping center, where land costs are lower and user amenity is a higher priority. Similar trade-offs may be made for the width of driving lanes, turning radii, floor-to-ceiling heights, driving and walking distances within the facility, traffic flow capacity, wait times at entrances and exits, and other aspects of the facility's design.

In this chapter, parking facilities are classified according to four *levels of service*, A through D. Level of Service A describes conditions that place the highest priority on user comfort and convenience; Level of Service D describes those placing the greatest emphasis on economy and the efficient utilization of space; and Levels of Service B and C represent intermediate conditions. In choosing a level of service for your project, the most important criteria are the familiarity of the user with the facility (familiar users can comfortably tolerate lower level of service conditions), the rate of parking turnover (with more vehicles moving through a facility at any given time, more generous dimensions should be provided to avoid conflicts or bottlenecks), and the expectations of the user (users accustomed to constrained parking conditions will be more tolerant of lower level of service conditions). Additional factors that may be considered in choosing the level of service for a facility include the following. Consider higher level of service designations for:

- Parking facilities in which users will frequently be carrying bulky packages or large materials
- Facilities used by the elderly or infirm
- Facilities serving family-oriented activities
- Outdoor parking in cold climate regions, where users wearing bulky clothing may have greater difficulty entering and exiting cars during periods of inclement weather
- Parking located in rural or suburban places where drivers are accustomed to readily available, less constrained parking

Lower level of service designations may be appropriate for:

- All-day or long-term parking
- Employee parking, residential parking, and other parking for repeat users who will be familiar with a facility
- Parking located in dense urban areas, where users are accustomed to congested traffic conditions and limited availability of parking

The following table provides recommended level of service ranges for parking serving various types of uses.

	Recommended Level of Service (LOS) Range			
Type of Use Served by Parking	**LOS A**	**LOS B**	**LOS C**	**LOS D**
Airports, Transportation Centers, all day and long-term		■	■	■
Airports, Transportation Centers, short-term	■	■		
Assembly Spaces such as theaters, sports arenas, cinemas, etc.	■	■		
Convention Centers	■	■		
Hospitals and Medical Centers	■	■		
Hotels		■	■	
Industrial Facilities			■	■
Office Buildings		■	■	
Residential			■	■
Retail, Shopping Centers	■	■		
Schools K-12		■	■	
Universities		■	■	■

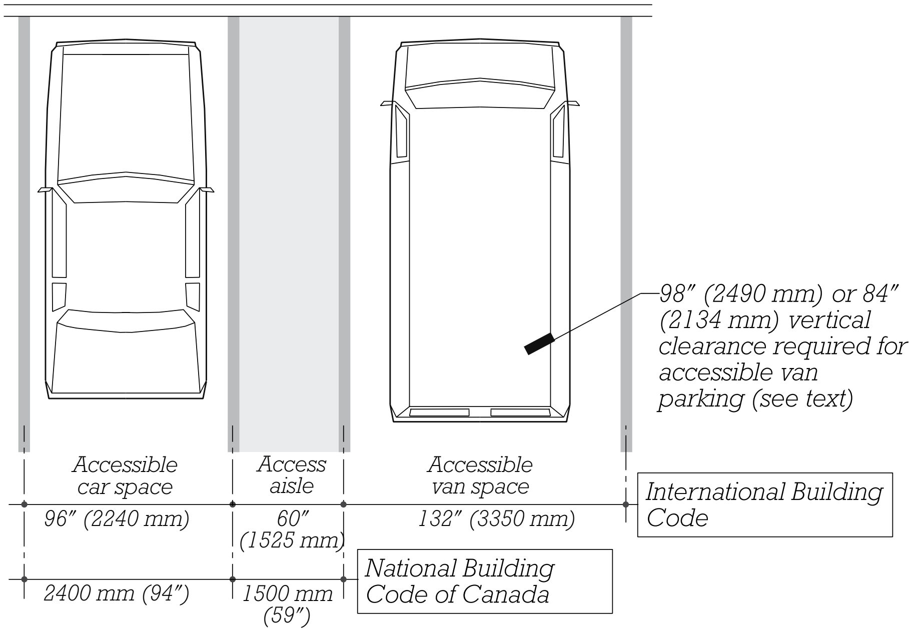
INTERNATIONAL BUILDING CODE

The International Building Code requires accessible parking wherever surface or structured parking facilities serve accessible buildings. This includes most building types except detached one- and two-family residences (see page 286 for more information). The table on this page lists the number of accessible spaces required for parking, depending on the building type served.

Where accessible parking spaces are required, one of every six spaces must be an accessible van space. In other words, where 1 to 6 accessible spaces are required, at least 1 must be accessible for vans; where 7 to 12 accessible spaces are required, at least 2 must be accessible for vans; and so on.

Accessible parking spaces must be located along the shortest accessible route to the building being served. Where there are multiple accessible entrances to a building, accessible parking spaces must be similarly dispersed. However, due to the special vertical clearance requirements of accessible van spaces, these may always be located solely on one level of a multilevel parking facility. Where accessible parking occurs on ramped tiers with slopes greater than 1:20 (5%), accessible routes must meet the requirements of accessible ramps.

Accessible car spaces must be at least 96 in. (2440 mm) wide, and accessible van spaces must be at least 132 in. (3350 mm) wide. Or, where the access aisle next to a van space is at least 96 in. (2440 mm wide), the van space itself need only be at 96 in. (2440 mm) wide. Accessible van spaces, and the parking facility aisles and lanes connecting these spaces to public roadways, must provide a minimum vertical clearance of 98 in. (2490 mm).



DIMENSIONS FOR ACCESSIBLE PARKING

Type of Use Served by Parking	Number of Accessible Parking Spaces Required by the International Building Code
Hospital outpatient facilities	10% of visitor and patient parking
Rehabilitation and physical therapy facilities	20% of visitor and patient parking
Occupancies R-2, R-3, and R-4, where required to provide Type A or Type B accessible units	2% of all parking, but not less than 1 accessible car space and 1 accessible van space
All other accessible buildings with:	
1–25 total spaces	1 accessible space
26–50 total spaces	2 accessible spaces
51–75 total spaces	3 accessible spaces
76–100 total spaces	4 accessible spaces
101–150 total spaces	5 accessible spaces
151–200 total spaces	6 accessible spaces
201–500 total spaces	6 accessible spaces, plus 1 per 100 (or fraction of 100) over 200
501–1000 total spaces	2% of the total number of spaces to be accessible
1001 or more spaces	20 accessible spaces, plus 1 per 100 (or fraction of 100) over 1000

Or, where such van spaces are located in private garages serving R-2 or R-3 Residential, Multifamily or Miscellaneous Occupancies, the required minimum vertical clearance is 84 in. (2134 mm).

All accessible parking spaces must have an access aisle, at least 60 in. (1525 mm) wide on at least one side, extending the full length of the space. One aisle can be shared by two accessible spaces, with one space on either side. Where accessible van parking spaces are angled, the access aisle must be on the passenger side of the van.

NATIONAL BUILDING CODE OF CANADA

The National Building Code of Canada refers to local jurisdictions for barrier-free parking requirements. In the absence of such requirements, the code provides guidelines recommending that wherever more than 50 surface or structured parking spaces are provided, barrier-free spaces should be provided at the rate of one per every 100 spaces; see the table on this page.

Barrier-free parking spaces must be located close to a barrier-free entrance to the building they serve. Long paths of travel should be avoided. Where barrier-free parking occurs on ramped tiers with slopes greater than 1:20 (5%), barrier-free routes must meet all the requirements of barrier-free ramps (see pages 290–291 for more information on barrier-free routes).

Barrier-free spaces must be not less than 2400 mm (7′-1″) wide and must be provided with an access aisle not less than 1500 mm (4′-11″) wide on at least one side. One aisle can be shared by two barrier-free spaces, with one space on either side.

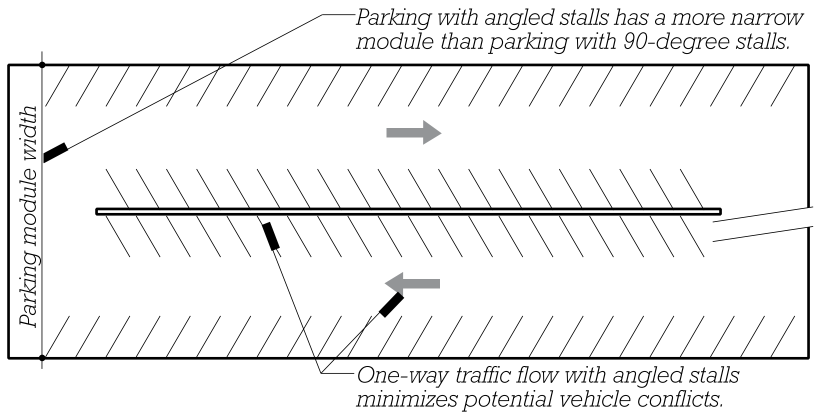
Number of Parking Spaces Provided	**Number of Accessible Parking Spaces Recommended by the National Building Code of Canada**
1–50 total spaces	None
51–100 total spaces	1 accessible space
101–200 total spaces	2 accessible spaces
201–300 total spaces	3 accessible spaces
301–400 total spaces	4 accessible spaces
401–500 total spaces	5 accessible spaces
501 or more total spaces	1 accessible space for every 100 total spaces (or fraction of 100 spaces)

2 CONFIGURING PARKING FACILITIES

This chapter will aid you in the selection of a circulation scheme for your parking facility, provide guidance on the design of other aspects of the facility, and, in the case of structured parking, offer recommendations for the choice of a structural system.

ENTRANCES AND EXITS

Parking facility entrances and exits should be located away from street intersections, especially busy ones. Entrances, suitably distant from intersections, may be located on streets with high volumes of traffic inbound to the facility, making them easy for drivers to find and access. Or, in congested areas, entrances may be located on secondary streets to minimize interference with traffic on more heavily traveled thoroughfares. Entrances should provide one lane for every 300 to 500 stalls of parking. Entrance lanes should be long enough to allow queuing of several vehicles ahead of control points or turns into parking aisles. In structured parking facilities on sloped sites, entrances should be located strategically to minimize ramping within the facility. For example, for below-grade parking, it is advantageous to locate entrances close to the low end of the site. Where entrances and exits are separate, exits may be located where they discharge onto low-traffic-volume secondary streets, helping to minimize backups within the facility or disruption of traffic on main thoroughfares during times of heavy use.



PARKING AISLE WITH ONE-WAY TRAFFIC FLOW AND ANGLED STALLS

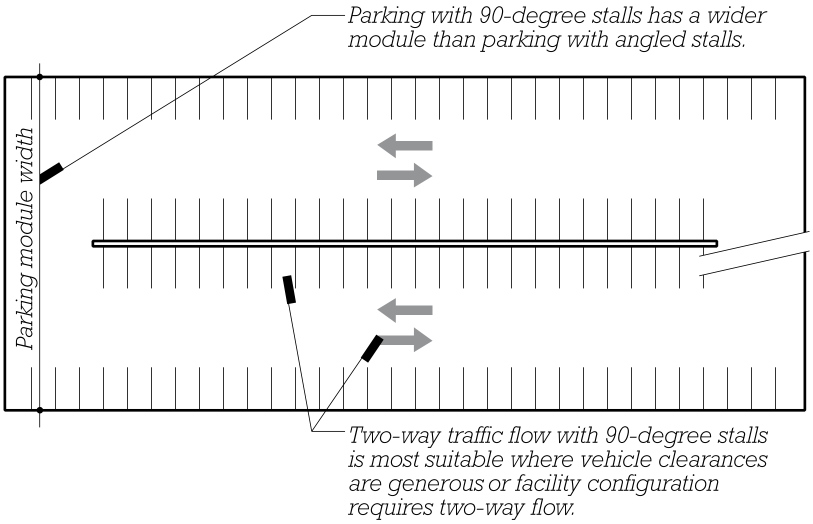
PARKING AISLES AND STALLS

Within parking facilities, the designer has a choice of one-way or two-way traffic flow. One-way traffic flow minimizes opportunities for vehicle conflicts and reduces opportunities for congestion in heavily used facilities. One-way traffic flow is especially advantageous for structured parking facilities where driver site distances tend to be limited and parking dimensions are constrained. With one-way traffic flow, parking stalls should be angled. Stalls angled 75 degrees to the flow of traffic result in the highest efficiency, that is, the least area required per stall. Stalls angled at 60 degrees, though less efficient, may provide more comfortable vehicle entry and exit. Stalls angled at 45 degrees are the least efficient but also result in a *parking module* of the least width, that is, in the least combined width of drive aisle and stalls on either side. Intermediate angles may also be used, but stalls should never be angled at less than 45 degrees or more than 75 degrees.

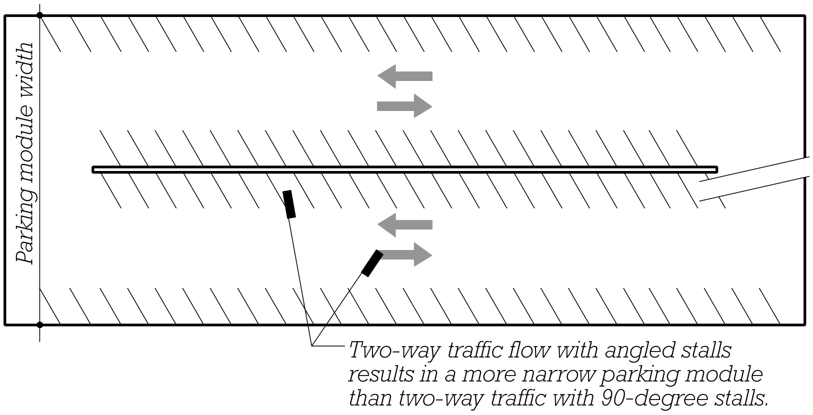
PARKING CIRCULATION BASICS

Two-way traffic flow is most suitable for facilities with generous vehicle clearances, for surface parking with multiple points of access where enforcing one-way flow is impractical, or where the configuration of structured parking requires two-way circulation. Where two-way traffic flow is provided, 90-degree parking stalls are preferred to allow the greatest flexibility in entering and exiting stalls from either direction. However, where a narrower parking module is required, angled stalls also may be used with stalls on opposite sides of aisles angled for flow in opposite directions. When comparing the space efficiency of 90-degree and angled stalls, two-way aisles with 90-degree stalls are typically about as efficient as one-way aisles with 75-degree stalls, as the greater compactness of the 90-degree stalls themselves is offset by the wider aisles required for two-way traffic circulation.

Circulation within a facility should be designed so that entering the facility, locating a stall, entering and exiting the stall, and leaving the facility require the fewest possible distinct vehicle maneuvers, such as turns or reversals in direction. Dead-end aisles should be avoided. The arrangements of stalls and aisles should be as consistent as possible from one section or tier of a facility to the next. There should be a logical, continuous route through the facility.



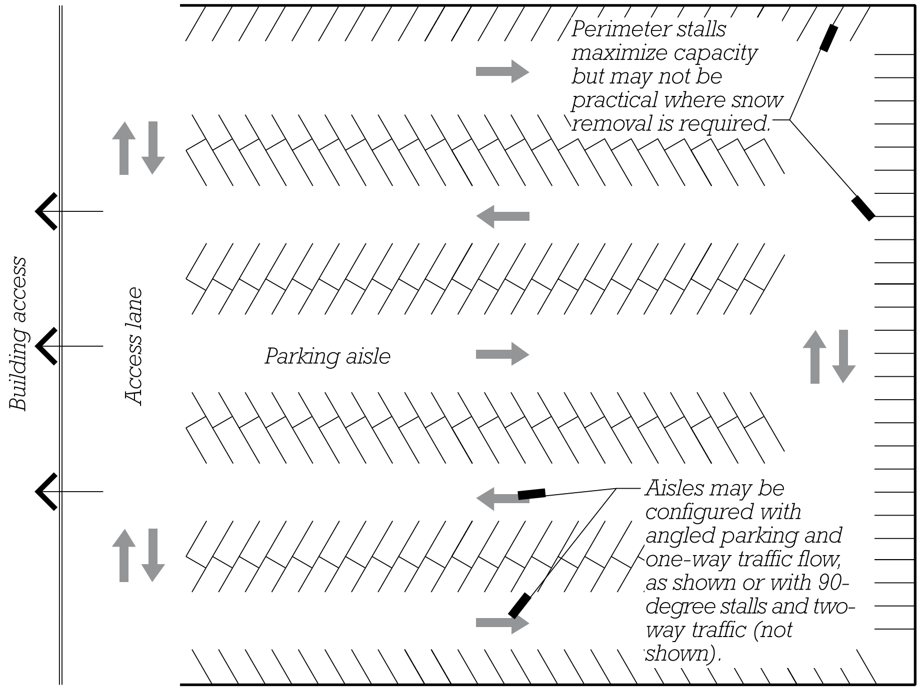
PARKING AISLE WITH TWO-WAY TRAFFIC FLOW AND 90-DEGREE STALLS



PARKING AISLE WITH TWO-WAY TRAFFIC FLOW AND ANGLED STALLS

SURFACE PARKING CIRCULATION

In its most common arrangement, surface parking is configured with an access lane located directly in front of the buildings served by the parking and with parking aisles aligned at right angles to the access lane. This arrangement permits passenger pickup and drop-off close to building entrances and allows pedestrian circulation between stalls and building entrances to occur within vehicle aisles. With long, narrow sites, stall efficiency may dictate that aisles be parallel to the longer dimension of the site. In this case, dedicated pedestrian pathways crossing rows of parking stalls may be required. Providing perimeter stalls, as illustrated in the accompanying diagram, increases stall efficiency but may interfere with snow removal in cold-climate regions. For the sizing of surface parking facilities, see pages 358–359.



EXAMPLE SURFACE PARKING CIRCULATION PLAN

LANDSCAPING

Where the priority is to maximize parking capacity, landscaping with trees and shrubs is customarily confined to areas unusable for parking, such as ends of stall rows, inaccessible corners, and so on. Alternatively, greater extents of landscaping may be incorporated into a facility to meet requirements set by local design ordinances, to enhance the facility's comfort and appearance, or to mitigate its ecological impact. (In such cases, the number of available parking spaces will be reduced from the quantities indicated in the sizing guidelines provided in this chapter.) Where provided, landscaping must not interfere with sight lines. Plants that produce foliage within the range of 3 to 8 ft (0.9 to 2.4 m) above the ground should be avoided. Plants should also be kept comfortably away from vehicles to prevent damage to vehicle finishes and to avoid interference with users entering and exiting cars.

SURFACE PARKING AND SUSTAINABILITY

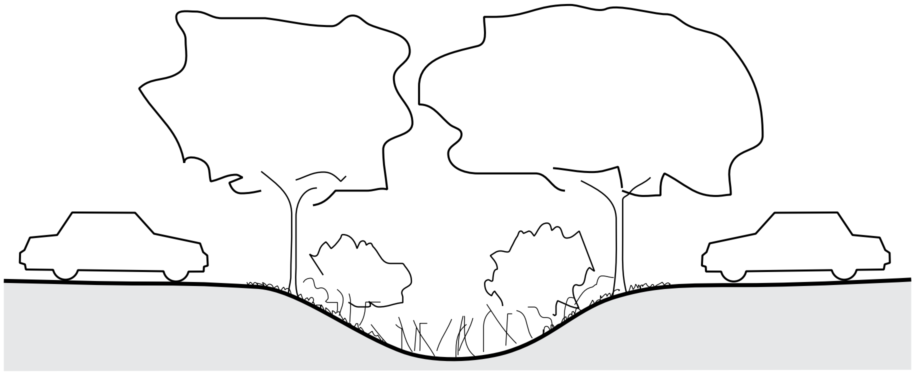
Surface parking consumes open land, reduces the quality of water in streams and lakes, and degrades the environment. Consider the following guidelines for minimizing these detrimental effects.

Reduce the Number of Parking Stalls: Reducing the number of parking stalls reduces the area consumed by parking. Where land-use regulations set requirements for parking capacity, design to the minimum permitted. Where capacity is established through analysis of demand, design to projected average demand rather than peak demand or work with neighboring facilities to share parking where peak use times differ (e.g., day and evening uses or weekday and weekend uses).

Reduce the Impervious Area: Reducing the impervious (paved) area reduces the volume and intensity of stormwater runoff, helping to protect natural water features. Design narrower parking stalls and less generous aisles and lanes; in other words, consider a lower level of service for the facility. Lay out stalls and circulation for maximum efficiency. Use pervious paving materials (ones that permit surface stormwater to pass through the paving to the ground beneath) for overflow parking areas. Consider structured parking as an alternative to surface parking.

Increase Planting: Plants and trees reduce stormwater runoff. They hold water in their leaves and on their branches and stems. Plant roots increase the permeability of soil and its capacity to absorb water. Plantings, especially canopy trees, reduce heat island effects. Planted areas also create wildlife habitat and a more aesthetically interesting environment.

Provide Natural Stormwater Retention: Stormwater directed into shallow landscaped swales can infiltrate back into the soil or be discharged from the site at a more controlled rate. Such bioretention areas also aid the removal of pollutants in stormwater runoff and can reduce the need for more expensive, traditional stormwater management facilities.



BIORETENTION SWALE

Minimize the Extent of Heat-Absorbing Surfaces: Reducing the area of heat-absorbing paving lowers the air and surface temperatures of a parking facility, thereby improving user comfort, reducing health risks, lowering the temperature of stormwater leaving the site, and even lessening the energy consumption of nearby buildings. By using shading, lighter-colored or pervious paving, and covered parking to reduce the absorptive area by 50% or more, significant improvements in heating effects can be achieved.

Avoid Development of Ecologically Valuable Land: Do not develop parking on prime farmland, in floodplains, on land providing habitat for endangered species, close to wetlands or productive bodies of water, or on land previously used as public parkland.

STRUCTURED PARKING CIRCULATION

This chapter provides design guidelines for four configurations of vertical circulation in structured parking: single-threaded helix, double-threaded helix, split-level, and multi-bay. These configurations are suitable for the preliminary design of efficient parking solutions meeting a broad range of requirements for facilities varying in size, use characteristics, and site constraints.

Single-Threaded Helix

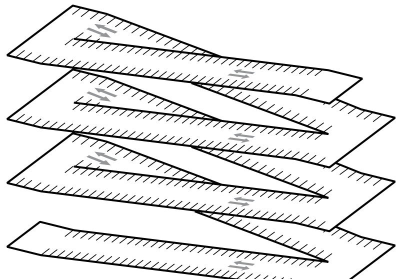
The *single-threaded helix* consists of a single continuously spiraling ramp, a configuration that is intuitively easy for users to navigate even when they are unfamiliar with the facility. An important characteristic of the single-threaded helix is that, being a single spiral, it cannot form a complete loop. Users leaving the facility must traverse in the opposite direction the same path used to arrive at their parking stall. Consequently, in their simplest form, single-threaded helix structures must be designed for two-way traffic flow. For the sizing of single-threaded helix structures, see pages 360–361.

Double-Threaded Helix

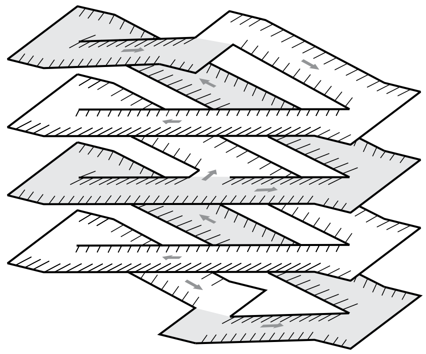
In a *double-threaded helix* configuration, two spiral ramps are intertwined so that a continuous loop is formed. Users traveling through such a facility can return to their original point of entry without ever retracing their path. A double-threaded helix structure can therefore be designed for one-way traffic flow, a configuration that minimizes congestion and conflicts between vehicles. This advantage is particularly important in facilities accessed by large numbers of users in relatively short time frames, where high peak vehicle flows create the greatest potential for traffic conflicts. In addition, users searching an entire facility for an available stall will have to pass each stall only once, since at the end of their search they will arrive back at the facility's entry. This is not the case in a single-threaded helix, where once users have searched all stalls, they arrive at the end of the spiral and must then retrace their path past the same stalls a second time in order to return to the place where they started. Double-threaded helix structures also allow for crossover aisles between adjacent ramps, providing shortcuts to facility exits. However, the double helix structure is also a less intuitive configuration and one that may be confusing to infrequent users. For the sizing of double-threaded helix parking structures, see pages 362–363.

Split-Level

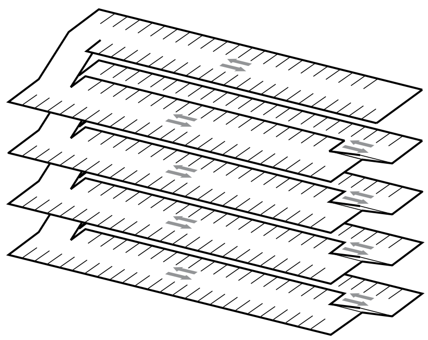
In a *split-level* parking structure, level parking tiers are connected by *speed ramps* at either end. Adjacent tiers are staggered in a manner that creates a vehicle circulation pattern similar to that of a single helix; that is, a closed loop is not possible, and two-way traffic flow is required. In a split-level structure, parking areas themselves are level, a benefit for user comfort and a feature that is particularly advantageous on constrained sites where bay lengths are short. As the length of the parking bay decreases in a single- or double-helix structure, ramps become more steeply sloped and increasingly uncomfortable for users. This is not the case for the split-level structure, where parking tiers remain level regardless of length. Split-level structures also conserve height (or depth in the case of below-grade structures) in comparison to ramped helix structures. For example, a three-bay split-level structure rises only as much as required for two ramps, since the first level is entirely at grade. In comparison, a three-bay single-threaded helix of similar extent and capacity must rise the combined height of three ramps. For the sizing of split-level parking structures, see pages 364–365.



SINGLE-THREADED HELIX CIRCULATION



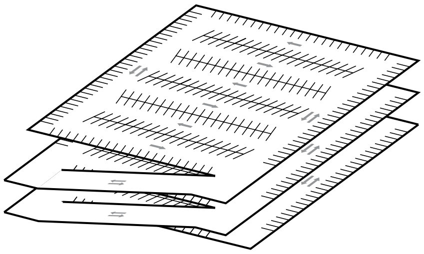
DOUBLE-THREADED HELIX CIRCULATION



SPLIT-LEVEL CIRCULATION

Multi-Bay

Multi-bay facilities consist of relatively large-area parking tiers without slope connected by internal ramped parking or external *express ramps*. Facilities of this type offer advantages of high capacity, high user comfort, and the capability to manage high peak flows. For the sizing of multi-bay parking structures, see pages 366–367.



MULTI-BAY CIRCULATION

Other Configurations

Variations on the circulation systems described above are also possible, although beyond the scope of this book to treat in detail. However, the overall capacity of such structures will not deviate significantly from the capacities derived from the charts in this text when considered on a proportional basis. In other words, for the purposes of preliminary design, an efficiently designed facility twice as wide as one designed using the charts in this book may be assumed to accommodate twice as many vehicles, and so on. Where more detailed information on such configurations is needed, consult the references listed in this book's bibliography.

STRUCTURED PARKING FACILITY DESIGN

The parking facility sizing information provided on pages 360–367 can be used to quickly determine the length, width, and height of a structure sufficient to provide parking for a specified number of vehicles. The dimensions provided by the charts account only for the parking system itself, that is, the ramps and aisles that vehicles use to circulate within the facility and the stalls in which they park. As explained in the text accompanying the charts, in some cases allowance is also made for the placement of structural columns or bearing walls. However, these charts do not account for other features such as stair towers, elevator shafts and lobbies, spaces for mechanical and electrical systems, and other possible items. In order to complete the preliminary design of a structured parking facility, the following requirements should also be considered and the necessary spaces and elements incorporated into the design as appropriate to your project's requirements.

Building Code Requirements

The maximum allowable height and area permitted for structured parking garages varies in each building code depending on Construction Type, Occupancy classification, types of vehicles stored, whether the garage is open or enclosed, and other variables. For height and area limits for parking garages constructed under

GIVE SPECIAL CONSIDERATION TO THE SYSTEMS INDICATED IF YOUR STRUCTURED PARKING FACILITY:	**Single-Threaded Helix (Pages 360–361)**	**Double-Threaded Helix (Pages 362–363)**	**Split-Level Helix (Pages 364–365)**	**Multi-Bay (Pages 366–367)**
Is planned primarily for infrequent visitors unfamiliar with the facility	●		●	●
Will be used primarily by regular users familiar with the facility		●		●
Is being constructed on a small, highly constrained site			●	
Will have high peak volume use		●		●
Is intended for large-capacity, high-volume parking				●

the International Building Code, see pages 444–447; for garages constructed under the National Building Code of Canada, see pages 476–479. If you do not know what building code applies to your project, see page 5.

Exterior Walls

The parking facility sizing charts provide the length and width of the facility measured to the inside of the exterior walls of the structure. To arrive at overall dimensions, the thickness of exterior walls must be added to these figures. For preliminary design purposes, thicknesses ranging from 6 to 12 in. (150 to 300 mm) may be assumed. Or, once you have selected a structural system for your facility, information on specific wall systems can be found on the following pages:

- Wood stud walls: pages 58–59
- Brick masonry walls: pages 84–85
- Concrete masonry walls: pages 90–91
- Steel stud walls: pages 94–95
- Sitecast concrete walls: pages 112–113
- Precast concrete wall panels: pages 130–131

Ventilation

Open parking structures must meet building code requirements for the extent of openings in exterior walls to ensure effective natural ventilation of the facility. If you do not already know which model building code applies to your project, see page 5.

In the International Building Code, each tier of an open parking structure must have exterior wall openings on at least two sides. These openings must be uniformly distributed, and their combined area may not be less than 20% of that tier's total wall area. In addition, where exterior openings are not located on opposite sides of the structure, their aggregate length may not be less than 40% of the total length of the perimeter of the tier. Interior walls must also contain uniformly distributed openings such that the tier remains at least 20% open. A minimum separation is required from any exterior face of the garage with openings, measured from the exterior face to the center of a public street or boundary of an adjacent private property. This distance varies from 5 to 30 ft (1.5 to 9.1 m) depending on the extent of wall openings and whether the building is sprinklered. For preliminary design of garages with minimum wall opening area, assume a minimum distance of 5 ft (1.5 m) for sprinklered buildings and 15 ft (4.6 m) for unsprinklered buildings. The parking of trucks, buses, or other large vehicles, the dispensing of fuel, and the repair of vehicles are all prohibited in open parking garages under this code.

The National Building Code of Canada requires each tier of an open parking garage to have exterior wall openings with an area totaling not less than 25% of that tier's total wall area (as viewed from the interior). These openings must be arranged to ensure cross ventilation for the entire tier. A minimum distance of 3 m (9.8 ft) is required from any exterior building face with openings to the center of a public street or boundary of an adjacent private property.

Enclosed garages, which rely on mechanical ventilation to remove hazardous gases and vapors, must include spaces for air-handling equipment and ductwork. Air intakes for the ventilation system must be located safely away from sources of potentially contaminated air (above the uppermost tier or roof level, for example), and exhausts must not discharge toward exterior occupied areas or walkways. In order to minimize ceiling height conflicts, main supply ducts should be routed vertically through the structure and located such that the size and extent of horizontal branch ducts can be minimized. Required ventilation rates for enclosed parking garages are relatively high compared to those of conventionally occupied buildings to ensure adequate air-handling capacity and the prevention of toxic gas accumulations. In order to reduce the high costs of continuously moving large quantities of air, many facilities rely on a system of carbon monoxide detectors to control ventilation rates, running the system at its highest capacity only when dangerous gas concentrations rise above specified levels. Cashier booths, offices, and other continuously occupied employee or public-use spaces within the facility should have their own dedicated supplies of conditioned, fresh air. For more information, see pages 191–192 for the design of fan rooms and pages 216–219 for the sizing of air-handling system components. When using the chart on page 219, read to the far right in the bands labeled for various building types.

Pedestrian Circulation

Pedestrian circulation within a single tier or floor normally occurs along the same aisles used by vehicles to access stalls. However, where the potential for hazardous conflicts between vehicles and pedestrians may occur, dedicated walkways or other safety measures should be provided. Examples of such areas include the top and bottom of ramps (especially steep ones), points where pedestrian or driver vision is limited, facility entrances and exits, places where automatic gates control vehicle movement, and so on.

To aid in wayfinding and maximize personal safety, pedestrian pathways should to the greatest extent possible provide a direct line of sight from car stalls to a level's primary entrance/exit, stairway, or elevator. For the same reason, exit stairs, elevator lobbies, and other components of the circulation system should be designed to be as open and transparent as possible. For user comfort, pedestrian routes within a facility should not exceed 350 to 700 ft (100 to 200 m) in total length, although they may be as long as 1200 ft (370 m) in facilities designed to low level of service standards. Exits must also comply with building code egress requirements. Information on the minimum number of exits, remoteness of exits, maximum travel distance, and other such criteria can be found beginning on page 270.

Facilities with more than two levels should provide elevators for vertical circulation. Elevators should be located prominently and as close as possible to the building or facility being served by the parking. Parking serving retail and office facilities should provide one elevator for approximately every 250 to 450 stalls. Parking serving special-use facilities with high peak demand will require a greater number of elevators, and large-area parking serving facilities such as airports or hospitals will require fewer. When elevators are provided, at least one exit stairway should be located nearby to provide alternative vertical circulation when elevators are out of service or wait times are excessive. For more information on the configuration and sizing of elevator systems, see pages 207–209.

OTHER REQUIREMENTS

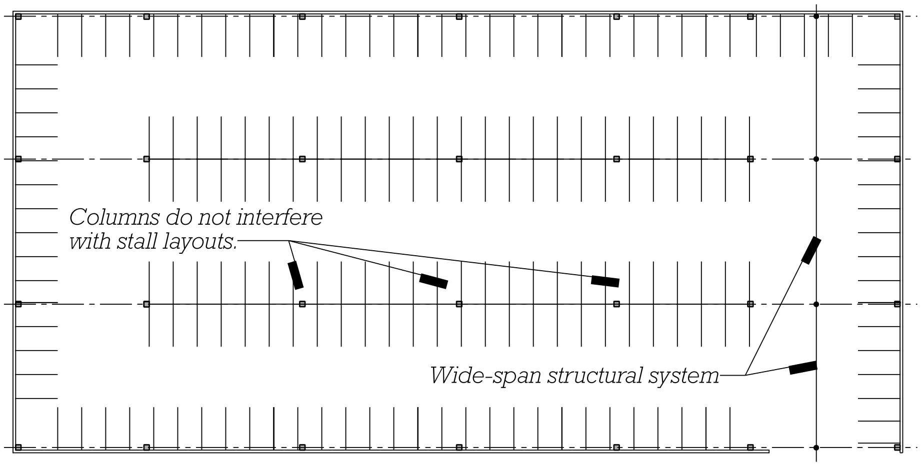
Other elements that should be considered in the design of a structured parking facility include:

- Structural systems: pages 353–354
- Accessible parking: pages 340–341
- Sprinkler systems: pages 208, 211–214
- Electrical closet: page 199
- Trash room for trash chute serving the facilities above: page 195
- Staff offices or workrooms: page 195
- Transformer vault and switch gear vault for primary electrical power service for adjacent facilities: pages 188–190
- Storage rooms
- Bicycle parking

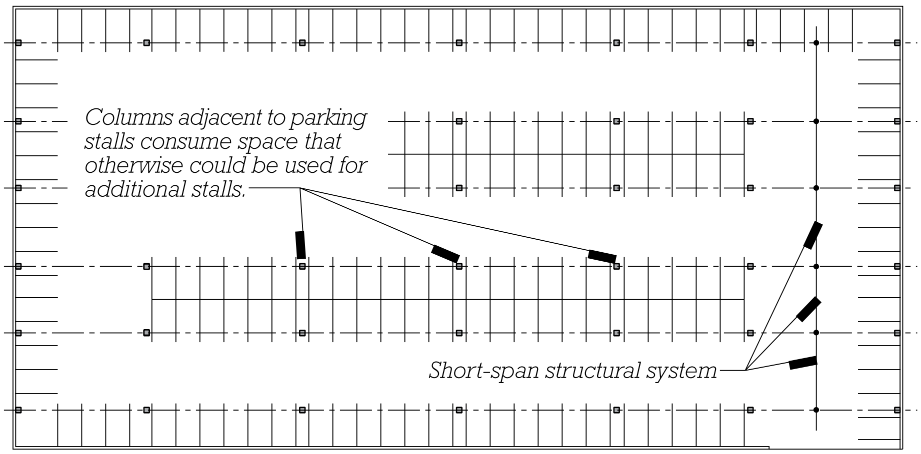
COLUMN LOCATIONS AND STRUCTURAL SPAN

Wherever possible, structural systems should be selected that can span the full width of one parking module, that is, the combined width of one drive aisle and the stalls on either side. For typical parking layouts, this dimension varies from 50 to 65 ft (15 to 20 m). In this arrangement, columns do not intrude between stalls, stall widths are not compromised, and the greatest flexibility in current and future stall layouts is preserved.

Where shorter-span systems are used, columns must be located between parking stalls. In this arrangement, column spacing must be coordinated with stall spacing, and stalls adjacent to columns must be widened to provide clearance for vehicle movement and to allow space for opening doors. The result is less flexibility in the layout of parking stalls and a reduction in the total number of stalls. However, where such configurations are used, span requirements for the structural system may be as low as 15 to 25 ft (5 to 8 m).



WIDE-SPAN STRUCTURE COLUMN LOCATIONS



SHORT-SPAN STRUCTURE COLUMN LOCATIONS

MIXED-USE BUILDINGS

In buildings where parking occurs above or below other uses, an important consideration is the coordination of structural elements between the different building parts. The building's primary vertical and lateral load-resisting systems must almost always be continuous from their highest point to the building's foundation. Other lines of load bearing must usually be vertically continuous to foundations as well, although in some circumstances and at significant cost, transfer structures may be used to shift the locations of such elements between different levels of a structure. Regardless of the approach taken, careful planning is required to develop structural configurations that are compatible with the requirements of the different parts of the building. In many cases, constraints on the placement of structural elements within the parking portion of the building may be the most restrictive, and the design of this portion of the building may have a strong influence on the entire structure, even to the point of dictating the column grid of the whole building. Due to the significant design and cost implications, the designer should thoroughly investigate the structural configuration of such mixed-use buildings at the earliest possible time. For more information on the configuration of structural systems, see pages 41–51, and for more information on the planning of service cores in buildings, see pages 196–198.

SELECTION OF STRUCTURAL SYSTEMS

Structural systems for structured parking facilities should be capable of spanning the required distances for optimum column placement within the facility and, in the case of open parking structures, should be resistant to the effects of precipitation, road salt, and other exterior conditions. The most commonly used systems are precast concrete, sitecast concrete, and structural steel.

Precast Concrete

Precast concrete is especially economical when used in repetitive configurations such as those that are common in parking garage construction; it is resistant to the effects of exterior exposure, and it does not require added finishes to attain an acceptable appearance or to be protected from fire. The most common precast concrete spanning system used in structured parking facilities is the double tee. Although single tees are also capable of spanning the required distances, they are less economical and less frequently used. Where span requirements are more modest, hollow-core planks may also be used. Guidelines for the design of precast concrete structures can be found on pages 127–137.

Sitecast Concrete

Like precast concrete, sitecast concrete does not require added finishes to attain an acceptable appearance or for protection from fire. Where sitecast concrete will be exposed to the weather, systems with very thin slab sections, such as one-way joist or waffle slab, should be avoided due to their vulnerability to corrosion of reinforcing. A post and beam system with posttensioned one-way or two-way slabs may be a more suitable option in these conditions. Posttensioning, in which reinforcing is prestressed after it has been cast, has several advantages for the construction of sitecast concrete parking structures: It increases spans while minimizing structural depth, and for structures exposed to the weather, it reduces cracking and improves the concrete's resistance to salts and corrosion. Guidelines for the design of sitecast concrete systems can be found on pages 109–125.

Structural Steel

Structural steel is also used for the construction of structured parking facilities. Where it is exposed to the weather, it must be protected by high-performance paint-like coatings, galvanizing, or other protective coverings to prevent corrosion. Where required, protection from fire is most economically provided with spray-on insulating materials. In open parking structures, materials applied for protection from fire, unless naturally weather-resistant, must themselves also be coated or covered to be protected from the weather. Steel structural systems for structured parking facilities take the form of a steel post and beam with either concrete-topped steel floor decking or precast concrete solid or hollow core slabs. Guidelines for the design of steel structural systems can be found on pages 93–108.

Building Code Height and Area Limits

Choice of a structural system for a structured parking facility is also limited by building code requirements. For parking facilities constructed to the requirements of the International Building Code, see pages 444–457, and for the National Building Code of Canada, pages 476–479. If you do not know what building code applies to your project, see page 5.

3 SIZING PARKING FACILITIES

This chapter will allow you to quickly determine the dimensions of a surface or structured parking facility to accommodate any required number of parking stalls.

GENERAL SIZING CRITERIA

The parking facility sizing charts on the following pages allow rapid determination of the overall dimensions of a parking configuration and the number of stalls accommodated. On this page, additional sizing information is provided for other aspects of the facility.

Access Lanes: For lanes without parking, a single lane should be 10 ft to 11 ft 6 in. (3000 to 3500 mm) wide, with an additional clearance to walls or other obstructions of not less than 6 in. to 2 ft (150 to 610 mm) on either side. A double lane should be 18 ft to 21 ft (5500 to 6400 mm) wide (for both drive lanes) plus the same side clearances as for a single lane. The outside radius of a turning lane should be 24 ft to 42 ft (7.3 to 12.8 m). Turning lanes are generally several feet wider than straight lanes.

Vertical Clearance within Structured Facilities: The International Building Code requires a minimum vertical clearance in parking structures of 7 ft 0 in.(2130 mm). The National Building Code of Canada requires a minimum of 2000 mm (6 ft 7 in.). Clearances of 7 ft 4 in. (2240 mm) or more improve user comfort, and this dimension may be increased to as much as 9 ft to 9 ft 8 in. (2740 to 2950 mm) in large facilities or those designed to high level of service conditions. Where accessible van parking spaces are provided, larger minimum clearances are required. See page 340 for more information.

Prior to selection of a specific structural system, overall depth of the floor structure may be estimated at 2 ft 6 in. to 3 ft (750 to 900 mm), assuming wide-span structural systems. For more information on choosing structural systems for structured parking, see pages 353–354.

Ramps: Ramped parking areas (see Single-Threaded Helix, pages 360–361, or Double-Threaded Helix, pages 362–363) should not exceed slopes of 5% (1:20) wherever possible. More steeply sloped parking areas are less comfortable for users, make car entry and exit more difficult, and must be treated as ramps where accessible routes are required. Where an accessible route is not required, parking ramps sloped up to approximately 7% (1:14) may be considered for facilities designed to lower level of service standards. In high level of service facilities, ramped parking areas should be minimized or eliminated to the greatest extent possible. See pages 286–290 for information on accessible routes in the International Building Code, or pages 290–292 for information on barrier-free routes in the National Building Code of Canada.

Speed ramps (see Split-Level, pages 364–365) should normally not exceed slopes of 12.5% (1:8). Steeper slopes may be acceptable in locales where drivers are accustomed to steep drives. Express ramps (see Multi-Bay Parking, pages 366–367) should not exceed slopes ranging from 8% to 16% (1:12 to 1:6).

Number of Tiers: The number of complete 360-degree revolutions required to reach the farthest stalls in a facility should normally not exceed six to seven. For facilities designed to a high level of service, fewer revolutions should be used.

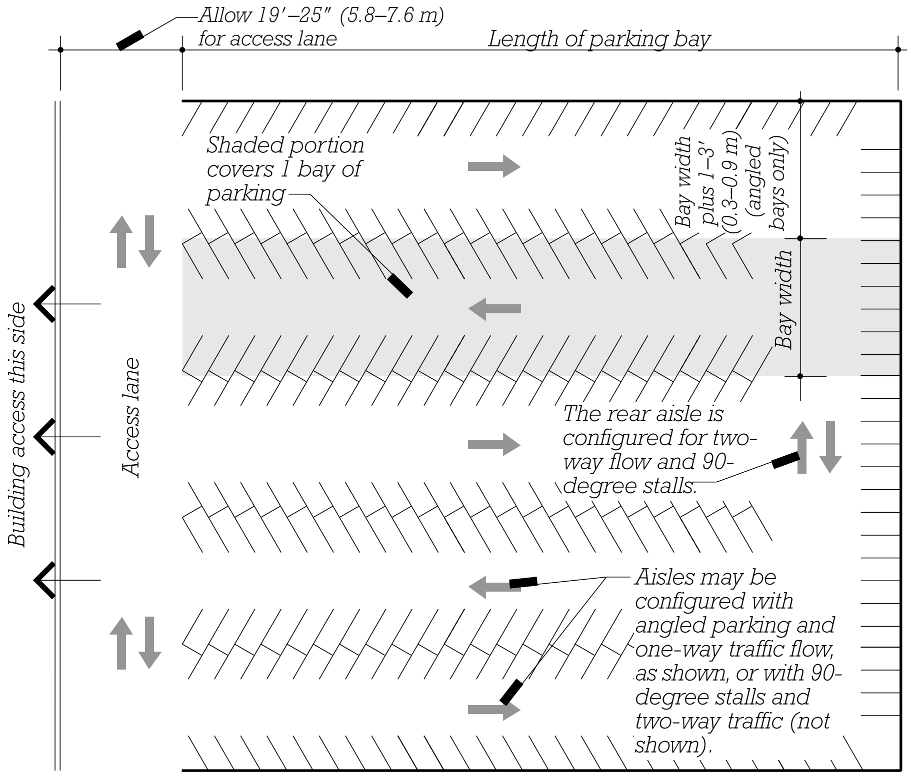
Stall Sizes: The parking facility sizing charts in this text are based on the assumption of uniform stall sizes throughout the facility. This approach is consistent with contemporary parking design guidelines that recommend against routinely providing a percentage of stalls sized for small cars only.This change from earlier practice reflects trends in the North American passenger vehicle population toward a larger percentage of wider vehicles and the lessening of the size difference between small and medium-sized cars. For the preliminary layout of individual standard stalls, a size of 8 ft 6 in. × 18 ft (2590 × 5490 mm) may be used.

Where the use of compact stalls is considered, they should be limited to not more than 10% to 15% of the total spaces in a facility. They may also be used in particular locations within a facility where a standard-sized stall will not fit, due to physical constraints. For preliminary design purposes, a compact stall size of 7 ft 6 in. × 15 ft (2290 × 4570 mm) may be used.

PARKING BAY WIDTH

On the charts on the facing page, *Bay width* is the width of one typical double-loaded parking aisle. Bay widths differ for each level of service, and are indicated on the chart for Level of Service A and D conditions. Within any band, widths for intermediate levels of service may be interpolated by adding or subtracting approximately 1 ft (300 mm) for each single step in level.

When configured with angled stalls, parking bays located at either end of the parking area will be 1 to 3 ft (300 to 900 mm) wider than the inner bays. To determine the overall width of the parking area, multiply the width of one bay by the number of bays and then add 2 to 6 ft (600 to 1800 mm) for the wider bays at either end. When configured for 90-degree parking, no special allowance for end bays is required, and parking area width is determined simply by the width of one parking bay multiplied by the number of bays.



EXAMPLE USE OF CHARTS

At least 500 stalls of surface parking are required as part of a suburban shopping center. The mall building is set back 450 ft from the main public roadway. Assuming high-turnover parking and users frequently accompanied by children or carrying bulky packages, Level of Service A conditions are proposed.

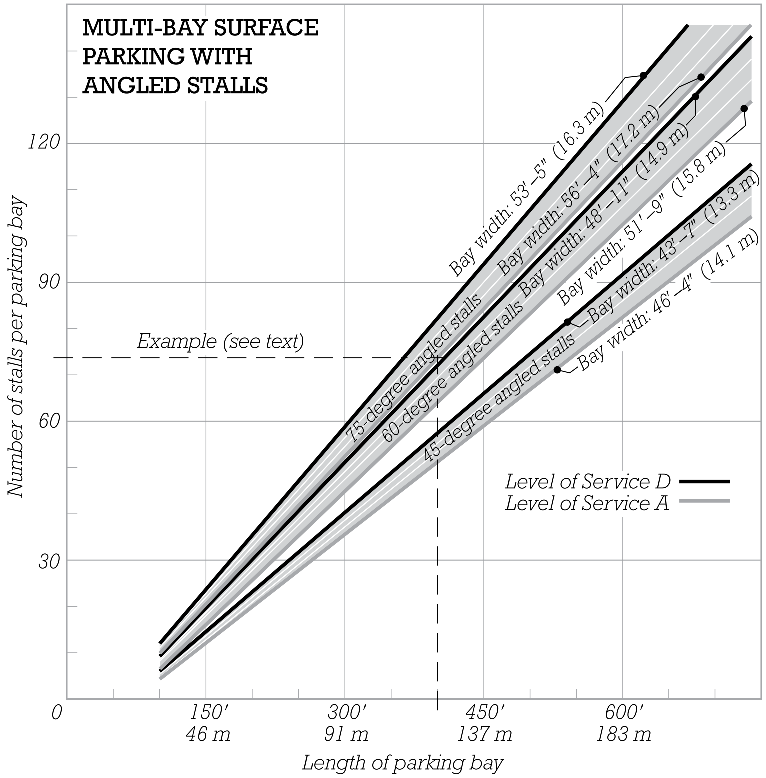
To provide the most convenient access to the mall building, parking aisles will be oriented perpendicular to the mall itself, as shown on the diagram on this page. To determine the space available for parking, 25 ft is subtracted from the building setback to account for landscape buffering, pedestrian walkways, and miscellaneous site features, and an additional 25 ft is subtracted to provide for the access lane running parallel to the mall entrance. The remaining available distance is 400 ft.

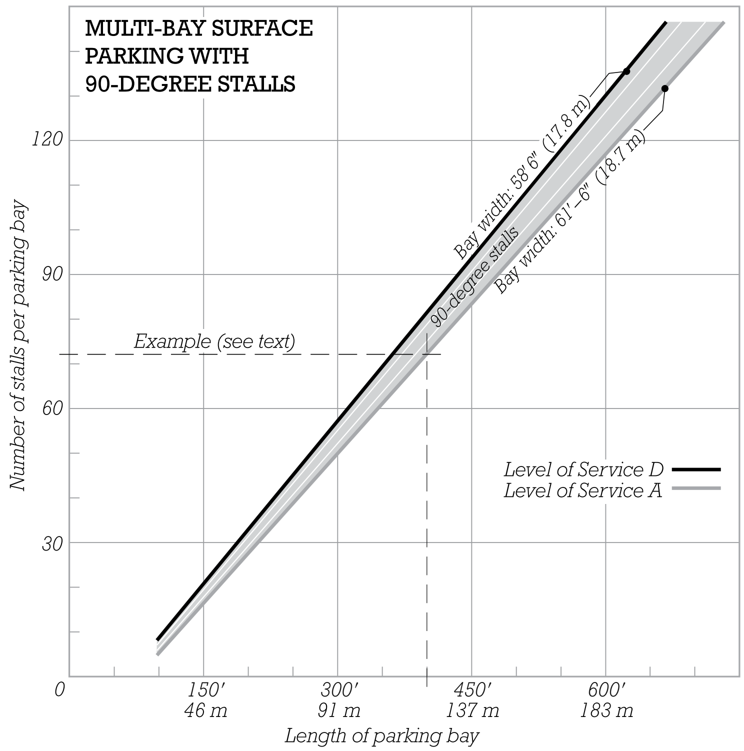
The first option considered is 75-degree angle parking with one-way traffic aisles. Reading from the upper chart on the facing page, we determine that a parking bay 400 ft long with Level of Service A conditions can accommodate 74 stalls in a bay 56 ft 4 in. wide. To accommodate the required number of stalls, seven bays are needed, providing 518 stalls (7 bays × 74 stalls per bay). To determine the overall width of the parking area, the width of one bay is multiplied by the number of bays, and an additional allowance of 3 ft is added to each side to account for wider end bays, as previously noted. The result is 400 ft 3 in. (7 bays × 56 ft 4 in. per bay + 2 × 3 ft end bay allowance).

As a possible alternative, parking with 90-degree stalls and two-way traffic aisles is also considered. Reading from the lower chart on the facing page, we determine that a parking bay 400 ft long with Level of Service A conditions can accommodate 72 stalls in a bay 61 ft 6 in. wide. Again, seven bays of parking are required, providing 504 stalls total. In this case, since end bays do not need to be widened, the overall width of the parking area is the width of one bay multiplied by the number of bays, or 430 ft 6 in. (7 × 61 ft 6 in.).

We conclude that either option is a viable configuration. If minimizing the land area occupied by parking is the higher priority, the angled parking solution may be used. Or, if providing the greatest flexibility in vehicle circulation is desired, the 90-degree parking solution may be chosen.

SIZING SURFACE PARKING





Use the two charts on this page to determine the length and width of a multi-bay surface parking facility as illustrated on the facing page. *Length of parking bay* is the length of one parking aisle and the adjacent perimeter aisle and stalls. *Number of stalls per parking bay* is the number of stalls within one bay (see the shaded area in the diagram on the facing page).

The top chart is for parking aisles configured primarily with one-way aisles and angled stalls.

■ Read in one of the three indicated bands for parking configured within the one-way aisles as either 75-, 60-, or 45-degree angled stalls. Within each band, read along the bottom for Level of Service A conditions (most generously dimensioned), or along the top for Level of Service D (most constrained). Intermediate Levels of Service B and C are also represented by the thin white lines within each band. See pages 338–339 for more information on selecting the appropriate level of service for your facility.

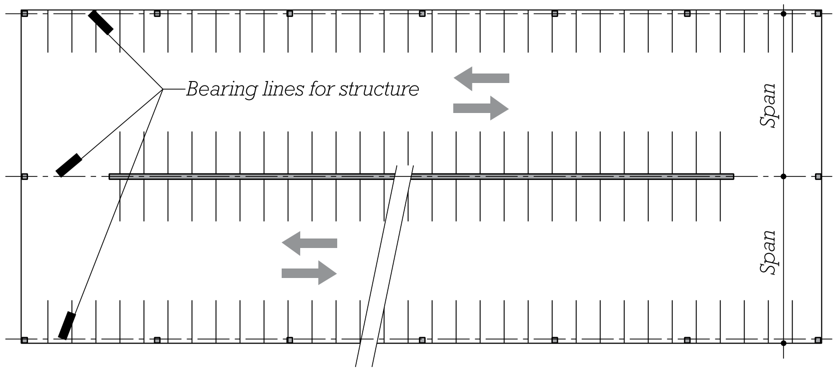
■ To determine the width of one parking bay, as well as the overall width of the parking facility, see the instructions for Parking Bay Width on the facing page.

The bottom chart is for aisles configured throughout for two-way traffic flow with 90-degree stalls.

■ Read along the bottom of the indicated band for Level of Service A conditions (most generously dimensioned), or along the top for Level of Service D conditions (most constrained). Intermediate Levels of Service B and C are also represented by the white lines within each band.

LOCATION OF COLUMNS AND BEARING WALLS

The dimensions read from the chart on the facing page (as well as those on pages 363 and 365) include allowances for columns and bearing walls located along three lines of bearing, as indicated in the adjacent diagram. Columns located along the perimeter may intrude up to 2 ft (0.6 m) into the ends of parking stalls or into the turning lanes at the ends of the ramps. A 2-ft (0.6-m) allowance is also provided for columns or a wall located along the bearing line between the ramps on either side. In this configuration, a floor system capable of spanning one-half of the total width of the structure is required. Shorter-span systems should be avoided, because, when columns fall between stalls, stalls must be widened, and the number of stalls per bay must be reduced. See page 354 for more information on selecting structural systems for parking structures.



EXAMPLE USE OF CHART

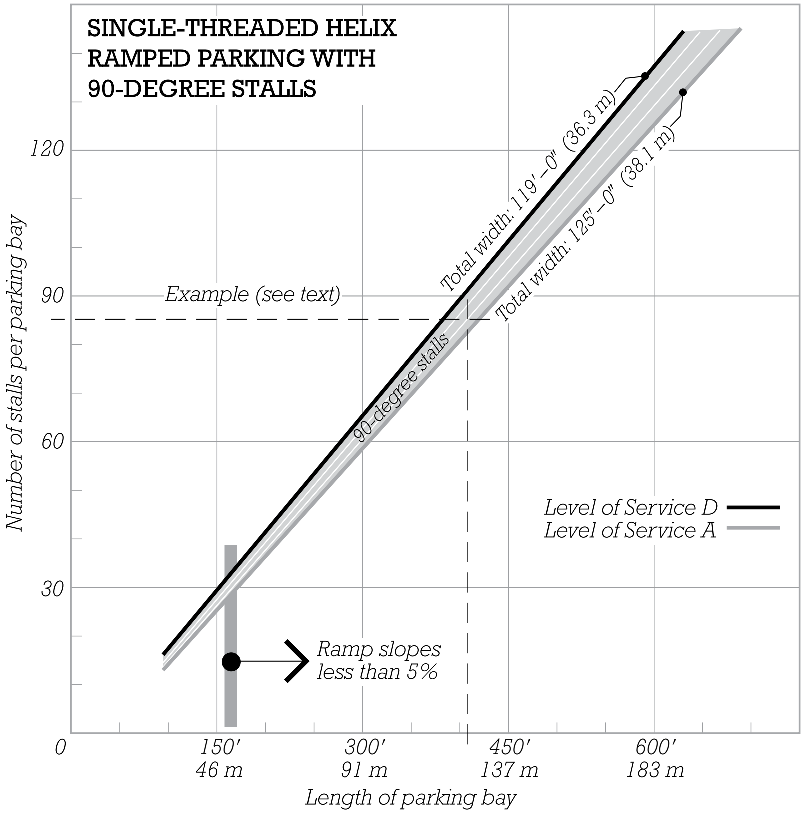
At least 500 stalls of structured parking are required for a small urban shopping complex. The site available for the parking structure is 420 ft long. Assuming mostly short-term parking and users unfamiliar with the facility, a single-threaded helix configuration is proposed, with two-way traffic, 90-degree parking stalls, and Level of Service B conditions.

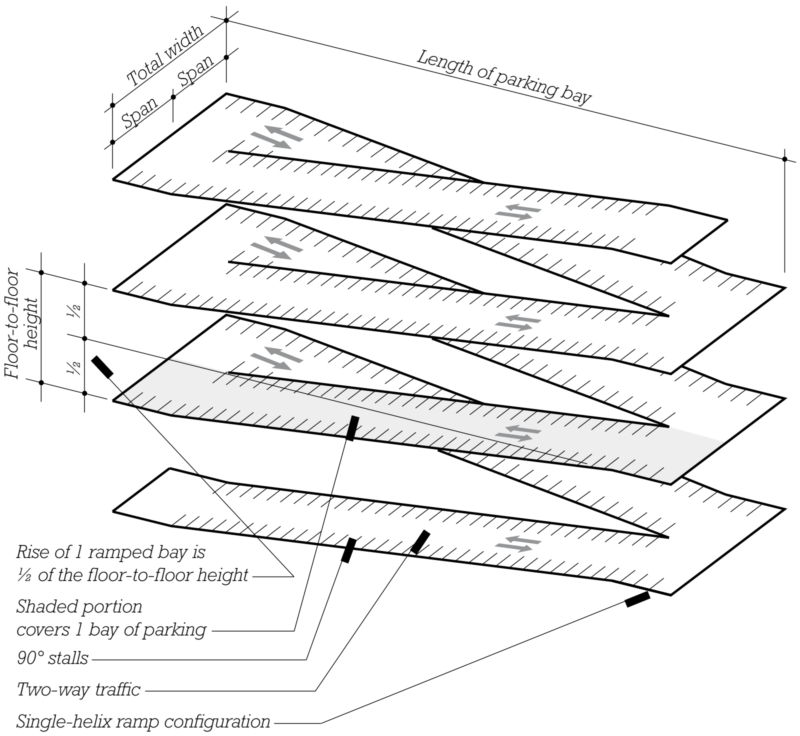
To determine the maximum possible length of the parking bays within the structure, 5 ft is subtracted from each end of the site to allow for site features and the thickness of exterior walls, resulting in a length of 410 ft. Referring to the chart on the facing page, we see that one such parking bay, sized for Level of Service B conditions, can accommodate 85 stalls. Six bays of parking will be required, providing 510 stalls total (six bays × 85 stalls per bay). Interpolating between the bay widths indicated for Levels of Service A and D, we determine that the width of the structure, excluding exterior walls, will be 123 ft.

To determine the height of the structure, we refer to the lower diagram on the facing page and note that each sloped bay of a single-threaded helix structure rises one-half of the structure's floor-to-floor height. Allowing 11 ft floor-to-floor, each bay will rise 5½ ft, and six bays of parking will have a total height of 33 ft (6 × 5.5 ft = 33 ft). Assuming that open-air parking is acceptable on the uppermost levels, no additional roof structure is proposed, and the height of the structure from its entrance to its highest parking level, excluding parapets, will be 33 ft. (For more information on floor-to-floor heights in structured parking, see page 357.)

In order not to compromise stall widths, structural systems considered for this facility should be capable of spanning one-half of its total width, or approximately 60 to 65 ft. Now that the configuration of the parking system itself has been completed, the next steps in this design process will be the consideration of pedestrian circulation, building systems, and other elements. See page 350–352 for more information on these subjects.

SIZING SINGLE-THREADED HELIX PARKING STRUCTURES





Use this chart to determine the length and width of a parking structure configured as a single-threaded helix ramp, with two-way traffic and 90-degree stalls. *Length of parking bay* is the dimension of the structure parallel to the ramps, excluding the thickness of exterior walls. *Number of stalls per parking bay* is the number of stalls within one parking bay (see the shaded area in the lower diagram).

■ Read along the bottom of the indicated band for Level of Service A conditions (most generously dimensioned), or along the top for Level of Service D (most constrained). Intermediate Levels of Service B and C are also represented by the white lines within each band. See pages 338–339 for more information on selecting the appropriate level of service condition for your facility.

■ *Total width*, which differs with each level of service condition, is the dimension of the structure perpendicular to the ramps, excluding the thickness of exterior walls. Total width is indicated on the chart for Level of Service A and D conditions. Within any band, widths for intermediate levels of service may be interpolated by adding or subtracting approximately 2 ft (0.6 m) for each single step in level.

■ To avoid parking ramps with uncomfortably steep slopes, read to the right of the vertical bar indicated for ramp slopes less than 5% (1:20).

■ Guidelines for incorporating pedestrian circulation, building systems, and other elements necessary to complete the design of a structured parking facility are provided on pages 350–352.

LOCATION OF COLUMNS AND BEARING WALLS

The chart on the facing page includes allowances for columns and bearing walls for a structural system spanning one-half of the total width of the structure. This structural configuration is discussed in more detail on page 353.

TOTAL WIDTH OF STRUCTURE

To determine the width of the structure, read *Total width* on the chart for the level of service condition. This is the width of the structure perpendicular to the ramps, excluding the thickness of exterior walls. Figures are provided for Level of Service A and D conditions. Within any band, widths for intermediate levels of service may be interpolated by adding or subtracting 2 ft (0.6 m) for each single step in level.

CROSSOVER AISLES

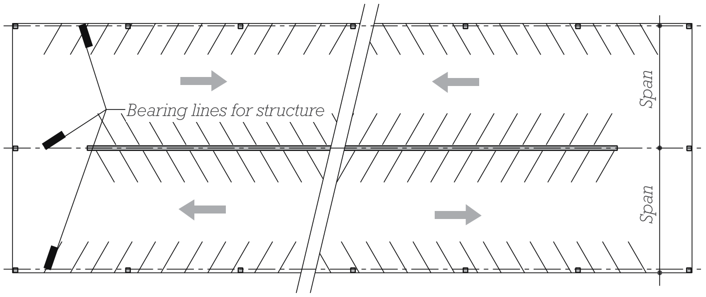
Figures provided on the chart allow for crossover aisles at every other pair of ramps, as illustrated in the lower diagram. If crossovers are provided at every crossing, stall totals will be reduced.

RAMP SLOPES

To avoid parking ramps with uncomfortably steep slopes, read only to the right of the vertical bar, as indicated for ramp slopes less than 5% (1:20).

EXAMPLE USE OF CHART

At least 255 stalls of structured parking are required as part of an urban office building complex. The site available for the parking structure is 265 ft long. Assuming mostly all-day parking and users familiar with the facility, a double-threaded helix configuration is proposed,



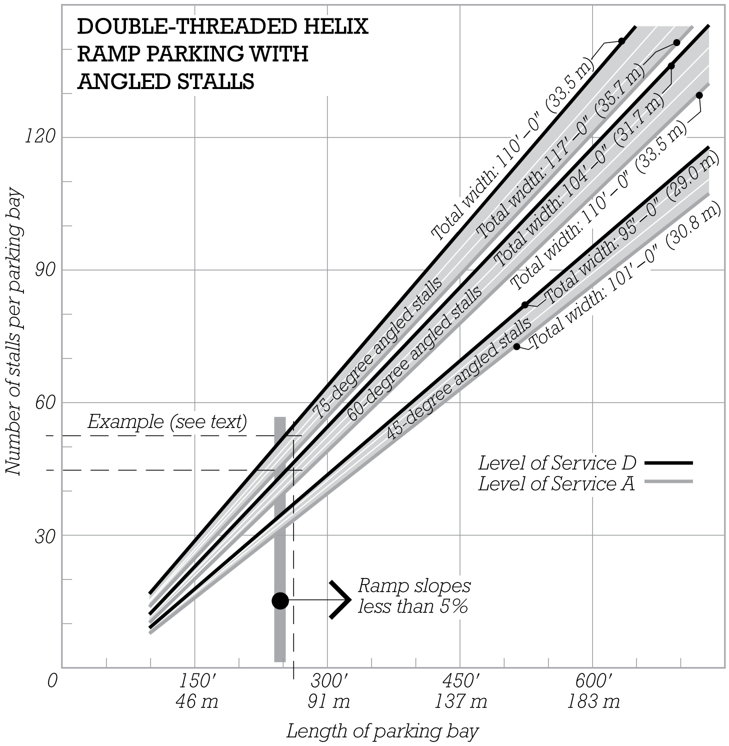
with one-way traffic, 75-degree parking stalls, and Level of Service C conditions.

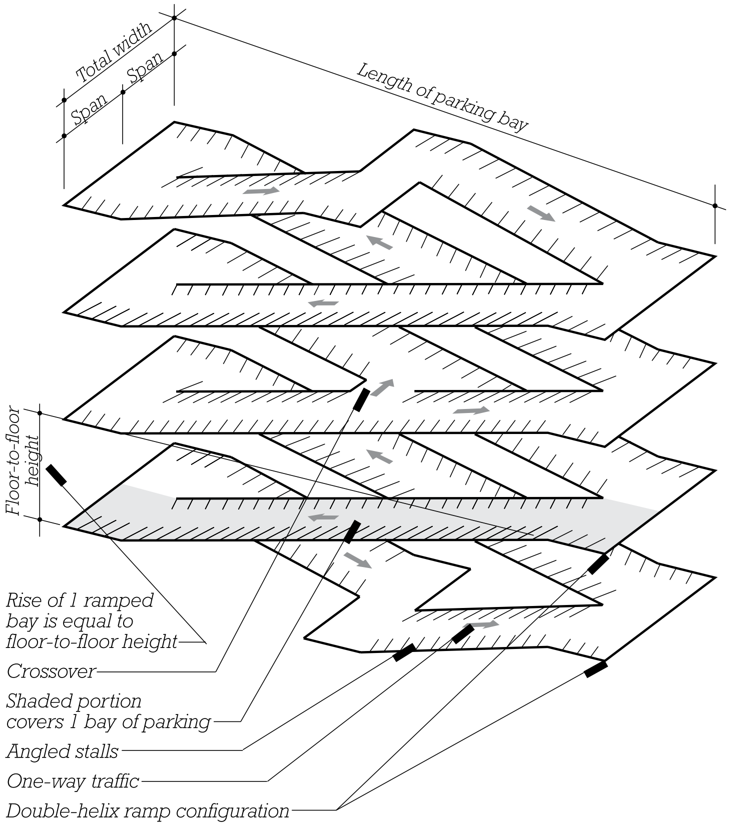
To determine the maximum possible length of the parking bays within the structure, 2 ft 6 in. is subtracted from each end of the site to allow for site features and the thickness of exterior walls, resulting in a length of 260 ft. Referring to the chart on the facing page, we see that one such parking bay with 75-degree angled parking and sized for Level of Service C conditions can provide 53 stalls. To provide the required 255 stalls, slightly more than five bays of parking are required. Referring to the diagram below the chart, we note that a double-helix structure must always be configured with an even number of parking bays (pairs of half-bays at the top and bottom, and pairs of full bays in between). In the proposed configuration, a four-bay structure can provide 220 stalls (four bays × 55 stalls per bay), an insufficient number, and a six-bay structure can provide 330 stalls (six bays × 55 stalls per bay), significantly in excess of the number required. One option to arrive closer to the required number of stalls would be to reduce the structure's length. However, studying the chart, we note that parking bays less than approximately 250 ft in length will have ramps with slopes greater than 5% (1:20), an important threshold for user comfort and accessible routes. So, we reject this option. Another option is to adjust the angle of parking stalls to 60 degrees. Although somewhat less space-efficient, 60-degree angled stalls are also more comfortable for parkers. In this configuration, each parking bay can accommodate 45 stalls, and six bays can provide a total of 270 stalls (six bays × 45 stalls per bay), slightly more than the number required. To determine the width of the structure, with Level of Service C conditions, we interpolate between the figures provided for Levels A and D for 60-degree angled parking and obtain a width of 106 ft.

To determine the height of the structure, we refer to the lower diagram on the facing page and note that each pair of bays of a double-threaded helix structure rises the same distance as the structure's floor-to-floor height. Allowing 10 ft floor-to-floor, each parking bay will also rise that same distance, and three pairs of parking bays will have a total height of 30 ft (3 × 10 ft). Assuming that the top bays of parking should be protected from the weather, an additional 10 ft is added for the roof level, and the overall building height is calculated as 40 ft from its entrance level to the top of the roof. (For more information on floor-to-floor heights in structured parking, see page 357.)

In order not to compromise stall widths, structural systems considered for this facility building should be capable of spanning one-half of its total width, or approximately 50 to 55 ft. Next steps in this design process would be the consideration of pedestrian circulation, building systems, and other elements. See pages 350–352 for more information.

SIZING DOUBLE-THREADED HELIX PARKING STRUCTURES





Use this chart to determine the length and width of a parking structure configured as a double-threaded helix ramp, with one-way traffic and angled stalls. *Length of parking bay* is the dimension of the structure parallel to the ramps, excluding the thickness of exterior walls. *Number of stalls per parking bay* is the number of stalls within one parking bay (see the shaded area in the lower diagram).

■ Read in one of the three indicated bands for parking configured within the one-way aisles as either 75-, 60-, or 45-degree angled stalls. Within each band, read along the bottom for Level of Service A conditions (most generously dimensioned), or along the top for Level of Service D (most constrained). Intermediate Levels of Service B and C are also represented by the thin white lines within each band. See pages 338–339 for more information on selecting the appropriate level of service condition for your facility.

■ In determining the number of bays required, note that double-helix structures must always have an even number of parking bays.

■ See the facing page for instructions on determining the overall width of the structure and further information on crossover aisles and ramp slopes.

■ Guidelines for incorporating pedestrian circulation, building systems, and other elements necessary to complete the design of a structured parking facility are provided on pages 350–352.

LOCATION OF COLUMNS AND BEARING WALLS

The chart on the facing page includes allowances for columns and bearing walls for a structural system spanning one-half of the total width of the structure. This plan configuration is discussed in more detail on page 353.

OVERALL WIDTH OF STRUCTURE

To determine the width of the structure, read *Total width* on the chart, which differs with each level of service condition. This dimension is the width of the structure perpendicular to the ramps, excluding the thickness of exterior walls. Figures are provided for Level of Service A and D conditions. Within any band, widths for intermediate levels of service may be interpolated by adding or subtracting 2 ft (0.6 m) for each single step in level.

SPEED RAMPS

The slope of the speed ramps in a split-level parking structure varies with the elevation difference between adjacent tiers and, to a lesser extent, with aisle dimensions derived from the stall angle and level of service condition. For preliminary purposes, elevation differences of greater than 5 ft (1.5 m) between adjacent tiers should be avoided, in order to avoid ramps with uncomfortably steep slopes of more than approximately 12.5% (1:8).

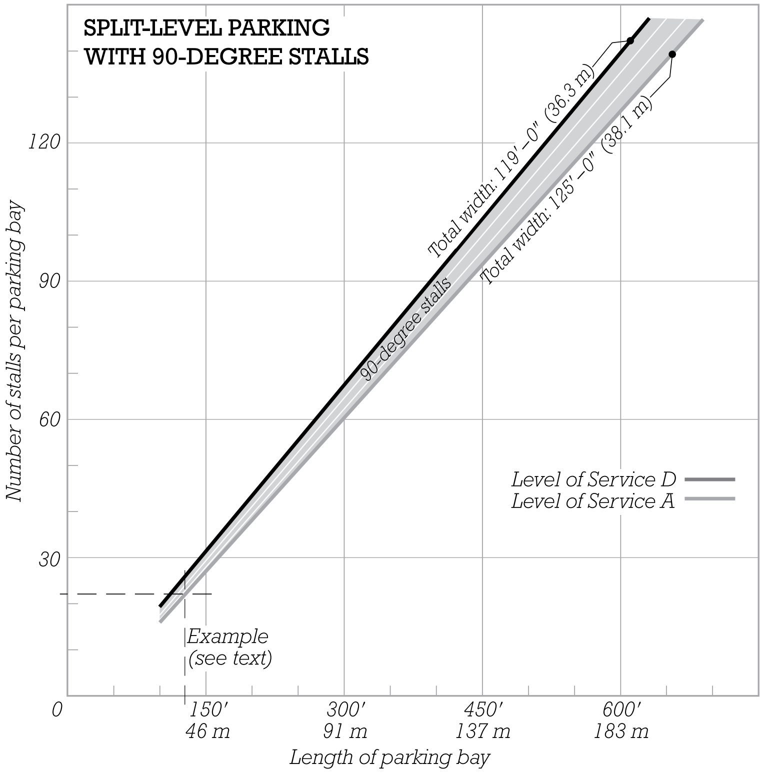
EXAMPLE USE OF CHART

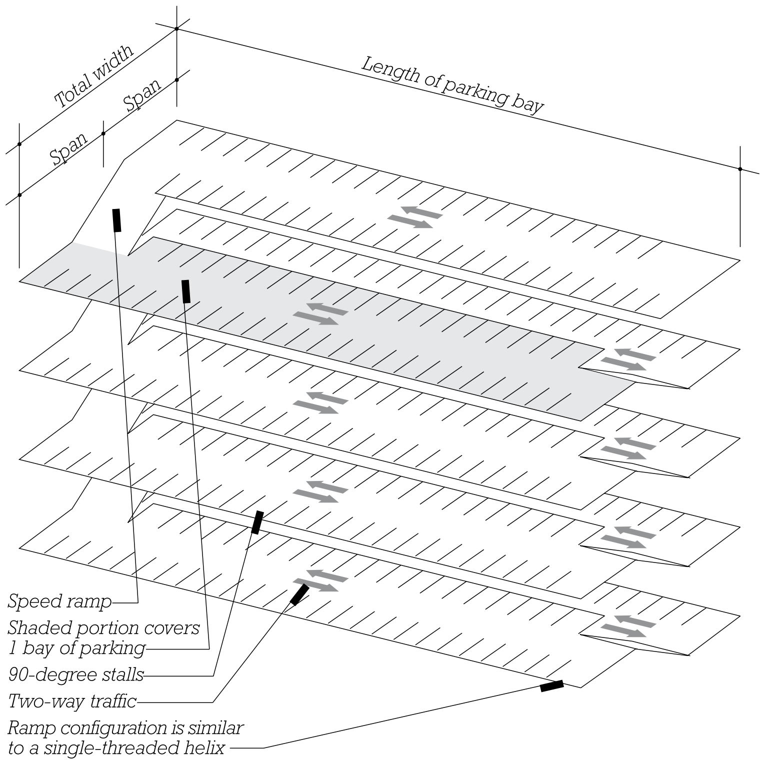
At least 55 stalls of Level of Service D structured parking are required beneath a condominium building in a dense urban setting. The building site is 130 ft long. Ramped single- and double-threaded helix structures have already been considered and rejected for this relatively small site, due to the uncomfortably steep slopes that would result within the stall areas.

To determine the maximum possible length of the parking bays within the structure, 2 ft 6 in. is subtracted from each end of the site to allow for the thickness of foundation walls and related construction, resulting in a length of 125 ft. Referring to the chart on the facing page, we see that such a parking bay can provide 23 stalls with Level of Service D conditions. Three bays of parking will be required, capable of providing up to 69 stalls. In this case, 55 stalls will be provided, and the excess area will be set aside for building service spaces. From the chart, we can also see that with Level of Service D conditions, the width of the structure within surrounding foundation walls must be at least 119 ft.

Referring to the lower diagram on the facing page, we see that a split-level parking structure is similar to a single-threaded helix in that the elevation change from one tier to the next is one-half of the structure's floor-to-floor height. Allowing 10 ft floor-to-floor, each parking bay will descend 5 ft. However, unlike the single-threaded helix, in a split-level structure the first bay of parking occurs entirely at the entrance level. In a three-bay structure, the lowest bay is only two tiers below the uppermost. Therefore, the lowest bay of parking will be only 10 ft (2 × 5 ft) below the entrance.

In order not to compromise stall widths, structural systems considered for this facility should be capable of spanning one-half of its total width, or approximately 60 ft. Now that the configuration of the parking system itself has been completed, the next steps in this design process would be the consideration of pedestrian circulation, building systems, and other elements. See pages 350–352 for more information on these subjects.



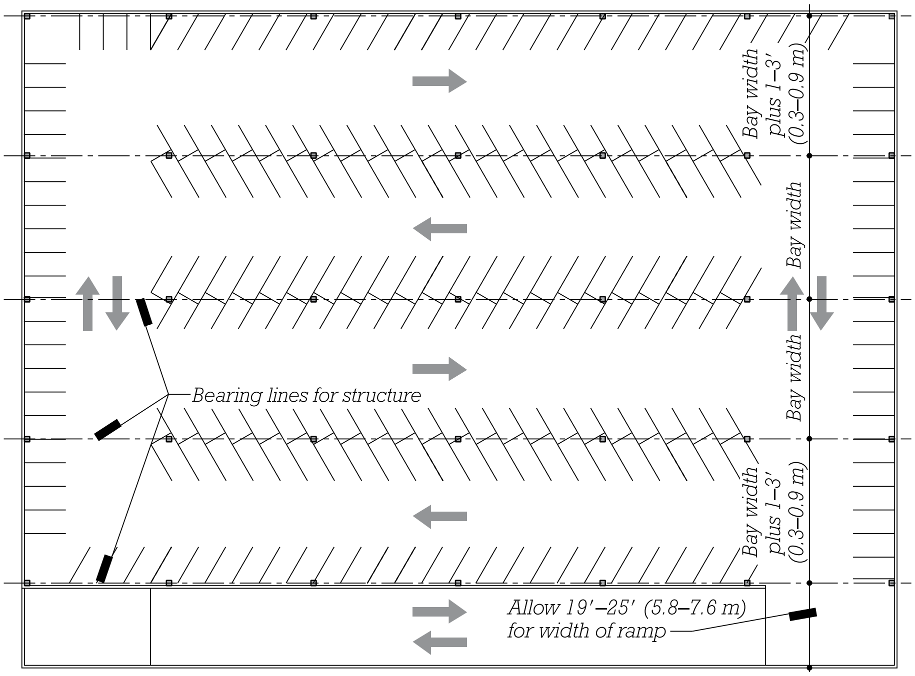


Use this chart to determine the length and width of a parking structure configured as split-level parking, with two-way traffic and 90-degree stalls. *Length of parking bay* is the dimension of the structure parallel to the parking aisles, excluding the thickness of exterior walls. *Number of stalls per parking bay* is the number of stalls within one parking bay (see the shaded area in the lower diagram).

■ Read along the bottom of the indicated band for Level of Service A conditions (most generously dimensioned), or along the top for Level of Service D (most constrained). Intermediate Levels of Service B and C are also represented by the white lines within each band. See pages 338–339 for more information on selecting the appropriate level of service condition for your facility.

■ See the facing page for instructions on determining the overall width of the structure and further information on ramp slopes.

■ Guidelines for incorporating pedestrian circulation, building systems, and other elements necessary to complete the design of a structured parking facility are provided on pages 350–352.



STRUCTURAL SYSTEMS

A structural system should be selected that is capable of spanning the full width of a single parking bay. Shorter-span systems should be avoided, because, when columns fall between stalls, stalls must be widened, and the number of stalls per bay must be reduced. See page 354 for more information on selecting structural systems for parking structures.

PARKING BAY WIDTH AND WIDTH OF STRUCTURE

On the chart on the facing page, *Bay width* is the width of one typical double-loaded parking aisle. Bay width differs with each level of service condition and is indicated on the chart for Level of Service A and D conditions. Within any band, widths for intermediate levels of service may be interpolated by adding or subtracting approximately 1 ft (0.3 m) for each single step in level. Parking bays located at either end of the parking area will be 1 to 3 ft (0.3 to 0.9 m) wider than inner bays. To determine the overall width of the parking area, multiply the width of one parking bay by the number of bays and then add 2 to 6 ft (0.6 to 1.8 m) for the wider bays at each end.

EXAMPLE USE OF CHART

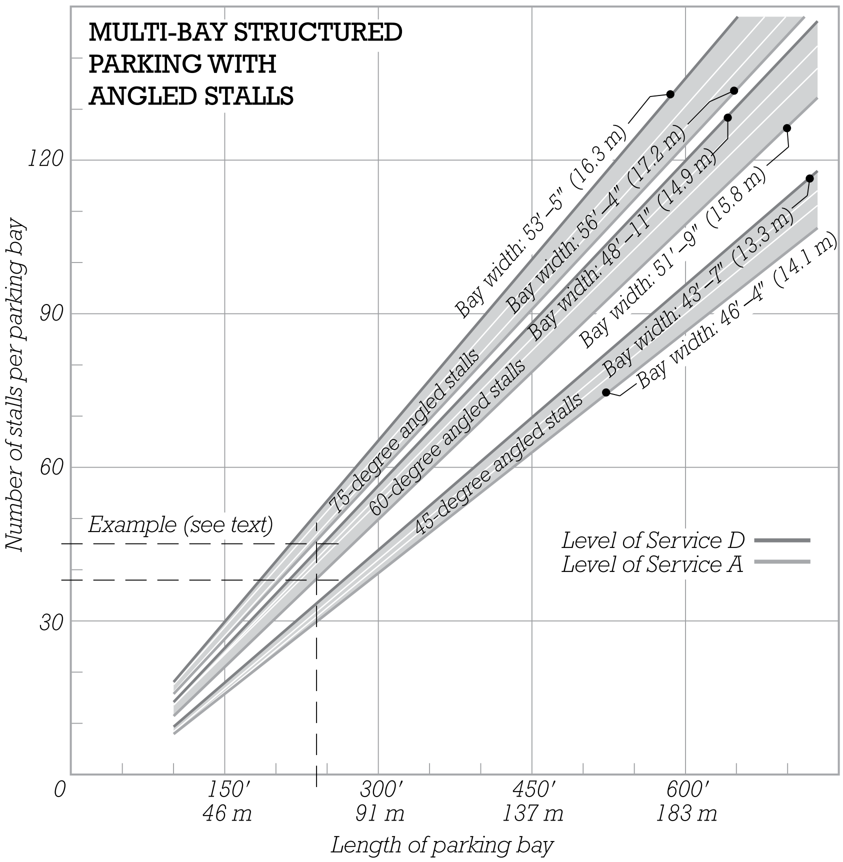
At least 950 stalls of parking are required for a regional airport facility. The building site is 260 ft in length in the direction parallel to the planned parking aisles within the facility, and 490 ft wide in the perpendicular direction. Assuming mostly short-term parking and users unfamiliar with the facility, Level of Service A conditions with 60-degree angled parking are proposed.

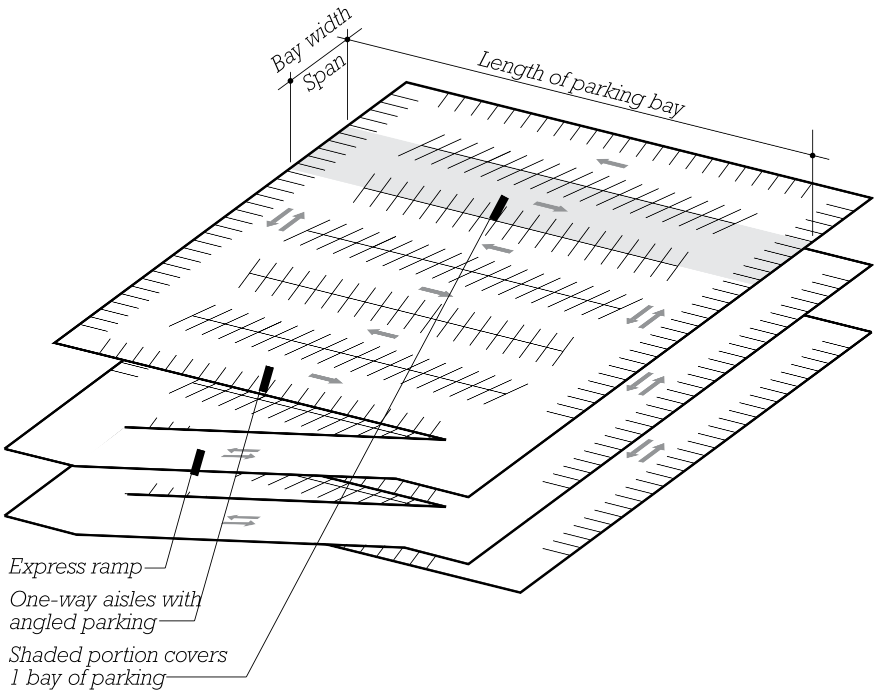
To establish the maximum possible length of the parking bays within the structure, 10 ft is subtracted from each end of the site to allow for site features and the thickness of exterior walls, resulting in a length of 240 ft. Referring to the chart on the facing page, we determine that such a parking bay with 60-degree angled stalls and Level of Service A conditions can provide 38 stalls in a bay 51 ft 9 in. wide.

To determine the width available for parking bays, we subtract from the width of the site 10 ft at each end for site conditions and exterior wall thickness, 25 ft at one end for the express ramp, 15 ft at the other end for various vertical circulation and building services, and 3 ft at each end for the wider parking bays required at the sides, as previously noted. The resulting width is 424 ft. Eight parking bays with an overall width of 414 ft (8 × 51 ft 9 in. per bay) and a total of 304 stalls (8 × 38 stalls per bay) can fit within this dimension. As an alternative, we also try a configuration with 75-degree angle stalls. In this case, a bay 56 ft 4 in. wide can provide 45 stalls of parking. Only seven bays can fit within the space, but with a total of 315 stalls in an overall width of 394 ft 4 in. In this second configuration, we can accommodate 11 more stalls per parking level in a structure roughly 20 ft smaller in width. We select the second option.

Assuming 11 ft 6 in. floor-to-floor heights and open-air parking at the top level, the top of the structure, not including parapets, will be 34 ft 6 in. (3 × 11 ft 6 in.) above the entrance level. Now that the configuration of the parking system itself has been completed, the next steps in this design process will be the consideration of pedestrian circulation, building systems, and other elements. See pages 350–352 for more information on these subjects.

SIZING MULTI-BAY PARKING STRUCTURES





Use this chart to determine the length and width of a large-area multi-bay parking structure configured with express ramps and a combination of one-way and two-way aisles, as shown in the lower diagram. *Length of parking bay* is the dimension of the structure parallel to the parking aisles, excluding the thickness of exterior walls. *Number of stalls per parking bay* is the number of stalls within one bay.

■ Read in one of the three indicated bands for parking configured within the one-way aisles as either 75-, 60-, or 45-degree angled stalls. Within each band, read along the bottom for Level of Service A conditions (most generously dimensioned), or along the top for Level of Service D (most constrained). Intermediate Levels of Service B and C are also represented by the thin white lines within each band. See pages 338–339 for more information on selecting the appropriate level of service condition for your facility.

■ Guidelines for incorporating pedestrian circulation, building systems, and other elements necessary to complete the design of a structured parking facility are provided on pages 350–352.

SECTION

7

DESIGNING WITH HEIGHT AND AREA LIMITATIONS

1 CONSTRUCTION TYPES AND HEIGHT AND AREA LIMITATIONS

This chapter explains how building code height and area limitations, Construction Type definitions, and related concepts influence the size and form of your building.

HEIGHT AND AREA LIMITATIONS

The model codes place limitations on building heights and areas in relation to the type of construction and the nature of the activities taking place within the building. This is done to ensure minimum standards of life and fire safety for the occupants of the building, as well as for surrounding buildings. Height and area limitations have the largest impact on building design of any code provisions, because they limit building size and dictate the types of construction from which the designer may choose.

Although both model building codes approach limitations on building height and area with similar goals, the particulars of how these requirements are defined and the results achieved differ between them. To the maximum extent possible, these differences have been minimized in the height and area tables provided in this text by presenting the data from both codes in a consistent format, allowing the designer to work as readily with one code as with the other. For example, the authors have adopted the names *3-Hour*, *2-Hour*, and so on for the Construction Types. These names are based on the required fire-resistance ratings of the structural loadbearing frame in each Type and are used to overcome inconsistencies in nomenclature between the codes. In addition, the adjustments permitted in each code for allowable area, height, inclusion of fire sprinklers, and other considerations have been precalculated to the greatest extent possible, for easy use.

One difference between the codes that was not possible to resolve relates to the determination of allowable area. For the International Building Code, tabulated values in the height and area tables are for the *total area of all floors of the building combined*. For the National Building Code of Canada, the tabulated values are for the *area of any single floor*. When working with these tables, be sure to apply the indicated values appropriately.

Each code has seemingly endless exceptions to its own basic height and area limitations. The most important of these deal with adjustments permitted in exchange for automatic sprinkler systems. These adjustments have been incorporated into the following tables. Other important conditions are noted in the accompanying text. Occasionally, exceptions are so complex that they cannot be

Use the indexes on these two facing pages to find the height and area limitations table for the building code and Occupancies you are working with

INTERNATIONAL BUILDING CODE

See pages 6–12 for more information on Occupancy classifications in the International Building Code.

HEIGHT AND AREA LIMITATIONS

NATIONAL BUILDING CODE OF CANADA

Occupancy	Height and Area Limits
A-1: Assembly, Theaters	452–453
A-2: Assembly, Miscellaneous	454–455
A-3: Assembly, Arenas	456–457
A-4: Assembly, Open Air	458–459
B-1: Detention	460–461
B-2: Medical Treatment	462–463
B-3: Care	464–465
C: Residential	466–467
D: Business and Personal Services	468–469
E: Mercantile	470–471
F-1: Industrial, High-Hazard	472–473
F-2: Industrial, Medium-Hazard	474–475
F-3: Industrial, Low-Hazard	476–477
F-3: Open-Air Garages	478–479

See pages 13–17 for more information about Occupancy classifications in the National Building Code of Canada.

easily simplified; for these, you are directed to the code itself. Some exceptions were deemed by the authors to be so minor as not to warrant their inclusion here. For this reason, you must carry out a thorough investigation of the building code itself as a building design progresses.

BUILDING HEIGHT AND AREA: RELATED CONSIDERATIONS

The following pages provide information on additional topics closely related to determining building height and area. You should review these pages to the extent that these conditions apply to your building design:

- For buildings containing more than a single Occupancy, see Mixed-Occupancy Buildings on pages 374–377. This section also describes scenarios in both model codes where different Occupancies can be combined with different Construction Types.
- Openings and connections between floors are addressed in Mezzanines, Floor Openings, and Atriums on pages 378–379.
- Fire protection and compartmentation are addressed in Fire Protection on pages 380–381. For example, the use of fire walls to divide large structures into separate buildings, each with its own Construction Type and limits on height and area, is explained on page 381.

NATIONAL BUILDING CODE OF CANADA, SMALL BUILDINGS

In addition to the height and area information provided in the tables later in this chapter, the National Building Code of Canada includes distinct requirements for *Housing and Small Buildings*, that is, buildings not greater than 600 m^2 (6458 sq ft) in horizontal extent, not greater than three stories in height, and serving only C Residential, D Business and Personal Services, E Mercantile, and F-2 or F-3 Medium- or Low-Hazard Industrial Occupancies. For preliminary design purposes, assume the following construction requirements.

- ¾-Hour Combustible or Noncombustible Construction is required (with some exceptions for roof and mezzanine construction).
- Depending on the proximity to other buildings, exterior walls may be required to be of Noncombustible Construction.
- Firewalls, used to create separate buildings, must be of Noncombustible Construction.
- Separation walls between two side-by-side C Residential Occupancies may be 1-hour rated Combustible or Noncombustible Construction.
- C Residential Occupancies must be separated from other Occupancies by assemblies with 1- to 2-hour fire-resistance ratings. Not more than one C Residential Occupancy suite may be mixed with F-2 Medium-Hazard Industrial Occupancy.
- In C Residential Occupancies, no fire-rated separation is required between a parking garage serving a single dwelling and that dwelling unit, provided that the construction between the dwelling unit and the garage is constructed as a barrier to the passage of gas and exhaust fumes, and doors from the garage do not open into rooms intended for sleeping.
- Sprinklers are not required, but may be used as a trade-off for various other code requirements.

Single buildings frequently accommodate more than one type of occupancy—for example, retail space on the ground floor of a multistory office building; restaurants, bars, and meeting rooms in a hotel; or parking garages beneath Business or Residential Occupancies.

When a building contains more than one Occupancy, the model codes generally require that the structure be classified as a single Construction Type throughout. That is, when considering the height and area limits for different Occupancies within the same building, the same Construction Type should be assumed for all. However, both codes also provide exceptions to this general rule, the most important of which are noted later in this section.

INTERNATIONAL BUILDING CODE

When two or more Occupancies are combined in one building, the International Building Code allows them to be treated as Nonseparated, Separated, Accessory, or Incidental Occupancies.

Nonseparated Occupancies

When occupancies are *Nonseparated*, they are permitted to remain open to each other, and there are no requirements for fire-rated separations between them. In this case, the allowable building height and area are determined by applying the most restrictive limits of any of the Occupancies to the entire building. For example, in a building including Nonseparated B Business, M Mercantile, and A Assembly Occupancies, the designer would consult the height and area limits for each of these occupancies, referring to the same Construction Type for each, and then apply the most restrictive limits of any of the occupancies to the building as a whole.

Within each Nonseparated Occupancy area, occupant load calculations, egress configuration, and other code restrictions are applied according to the requirements for that particular occupancy.

When the code height and area limits are generous enough to permit the treatment of a mixed-occupancy building as Nonseparated, this is the simplest method to apply and the one that affords the greatest design flexibility within the building.

Separated Occupancies

When mixed Occupancies within a single building are treated as *Separated*, the code defines fire-resistance rating requirements for walls and floor/ceiling assemblies between the different occupancies. These separations reduce the risk that fire and smoke in one area of the building can spread rapidly to others. In exchange for this added protection, greater building height and area are permitted. As with Nonseparated Occupancies, the same Construction Type is used for all height and area determinations.

Occupancy Separations: Separation requirements depend on the particular Occupancies. In the following table, where Occupancies are listed together in the same row, no separation is required even when they occur together within a Separated Occupancy building. However, Occupancies listed in separate rows must be separated from each other by construction with a fire-resistance rating of from 1 to 2 hours. For example, in a building including B Business, M Mercantile, and A Assembly Occupancies, the B and M Occupancies may remain open to each other, but the Assembly Occupancy area must be separated from the others by fire-resistance rated walls and floors. High-Hazard Occupancies are not included in the table. Where permitted in mixed-occupancy buildings, they must always be separated from other occupancies, sometimes by construction with fire-resistance ratings as high as 3 or 4 hours. Some High-Hazard Occupancies may not be mixed with other Occupancies at all.

SEPARATION REQUIREMENTS IN SEPARATED OCCUPANCY BUILDINGS

Occupancies on the same row do not require separation. Occupancies on different rows must be separated by fire-resistance rated construction of from 1 to 2 hours.
A, E
I-1, I-3, I-4
I-2
R
F-2, S-2, U
B, F-1, M, S-1

Height Limitations: In a Separated Occupancy building, each Occupancy area is required to conform to its own height limitations, both in number of stories and in feet or meters above grade. For example, in a four-story Separated Occupancy building, where one of the occupancy's height limitations restricts it to no more than two stories, that Occupancy may only be located on the first or second floor of the building. Some other Occupancy, with height limits permitting four stories, may be located on any floor.

Area Limitations: Where an entire building floor contains only a single Occupancy, the area of that floor is limited by the restrictions for that Occupancy. Where a floor shares two or more Occupancies, the allowable area determination for that floor is based on a proportional calculation, as follows:

1. For each Occupancy, divide its proposed area on the floor by the maximum area permitted by the code to get a decimal fraction.

2. Add the fractional results for each Occupancy on the floor.

3. The sum total must not exceed 1.

For example, consider a four-story university building, sprinklered, of Type II-A Construction. The proposed footprint of the building is 85,000 sq ft. On the first floor are three 5000-sq-ft auditoriums classified as A-3 Assembly Occupancy, and 70,000 sq ft of classroom space classified as B Business Occupancy. In the height and area limit tables on pages 400–401 and 406–407 the allowable single-floor areas in multifloor buildings for these two Occupancies are 46,500 sq ft for the Assembly Occupancy and 112,500 sq ft for the Business Occupancy (these figures are read from the bottom row of the height and area limit tables). To check the floor area, first divide the proposed area by the allowable area for each Occupancy:

Occupancy A-3, area on floor 1:

$$\frac{3 \times 5000 \text{ sq ft } \textit{proposed on floor } 1}{46{,}500 \text{ sq ft } \textit{allowed per floor}} = 0.32$$

Occupancy B, area on floor 1:

$$\frac{70{,}000 \text{ sq ft } \textit{proposed on floor } 1}{112{,}500 \text{ sq ft } \textit{allowed per floor}} = 0.62$$

Then sum the fractions and compare to 1:

$$0.32 + 0.62 = 0.94 < 1 \text{ OK}$$

In this case, the sum of the fractions is less than 1, and this combination of Occupancies is within allowable area limits. In a building with more than one floor, this check must be performed for each floor. (These additional checks are omitted in this example.)

For Separated Occupancy buildings over three stories in height, an additional check must be made to verify area limits for the building as a whole. In this case, a similar proportional calculation is performed, but considering the proposed area on all floors. Continuing with the example above, assume that the second through fourth floors of the building each contain 85,000 sq ft of classroom and office space, all classified as Group B Business. First, for each Occupancy, divide the proposed area on all floors by the allowable area for a single floor:

Group A-3:

$$\frac{3 \times 5000 \text{ sq ft } \textit{proposed all floors}}{46{,}500 \text{ sq ft } \textit{allowed per floor}} = 0.32$$

Group B:

$$\frac{70{,}000 \text{ sq ft} + 3 \times 85{,}000 \text{ sq ft } \textit{proposed all floors}}{112{,}500 \text{ sq ft } \textit{allowed per floor}} = 2.89$$

For this multistory check, the sum of the fractions must never be greater than 3:

$$0.32 + 2.89 = 3.21 > 3 \text{ NOT OK}$$

In this case, considering the area on all floors of the building, the sum of the fractions exceeds 3, and the proposed building is not within the code's area limits for the proposed mix of Occupancies. To solve this problem, the building area must be reduced, the mix of Occupancies must be adjusted, or a Construction Type with greater allowable areas must be selected.

Accessory Occupancies and Incidental Uses

Occupancies of limited area that are ancillary to another primary Occupancy may be treated as Accessory. This approach may result in relaxed separation requirements and/or reduced constraints on building height and area in comparison to other approaches to mixed occupancies.

One or more occupancy areas may be considered *Accessory* when, in total, they occupy no more than 10% of the area of the floor on which they are located. In most cases, no separation is required between Accessory and primary Occupancy areas, and building height and area requirements are governed by the primary Occupancy. Occupant load, egress, and sprinkler requirements for each Occupancy are applied individually to each area. Additionally, Accessory areas themselves may not exceed the unsprinklered area limits (regardless of whether sprinklers are present) for their particular Occupancy type. Certain Occupancies, such as High-Hazard, may not be treated as Accessory to others, regardless of area.

Incidental Uses are a list of particular types of spaces considered to have unique fire- or life-safety risks. Like Accessory Occupancies, spaces may be considered Incidental when they do not exceed 10% of the area of a floor. Incidental uses do not affect building height and area limits. However, they must meet the fire or smoke separation and sprinkler requirements specific to each listed use. Examples include furnace rooms, boiler rooms, incinerator rooms, machinery rooms, paint shops, laboratory areas, vocational shop areas, laundry rooms, waste and linen collection rooms, fire pump rooms, and others. See the code for more information.

Construction Type Separations

The International Building Code recognizes unique Occupancy combinations that result in different Construction Types, one above or below the other. The advantage to these scenarios is the possibility of building to a greater height with less expensive methods than would otherwise be permitted. In each of the following cases, each portion of the structure must meet the height and area limits for its Occupancies and Construction Type unless otherwise indicated.

3-Hour Horizontal Building Separation

When a 3-hour horizontal assembly separates upper and lower portions of a structure, each portion may be treated as follows:

■ The portion of the structure below the separation must be constructed of 3-Hour (Type IA) Construction and fully sprinklered. It may include any Occupancies other than H.

■ The portion of the structure above the horizontal separation may be of any normally allowed Construction Type and may include multiple Assembly Occupancies each with an occupant load of less than 300, as well as B, M, R and S Occupancies.

■ Each portion of the structure must comply with the area limits and number of floors applicable to the Construction Type and Occupancies of that portion.

■ The height of the entire structure, in feet or meters, is measured from the ground plane and may not exceed the limits of either portion.

R Occupancy over Open or Enclosed Parking

When a structure up to the first story above grade includes only S-2 Occupancy parking and is separated from any R Occupancy above by a (usually 2-hour) rated horizontal assembly, it may be treated as follows:

■ For enclosed parking, the portion of the structure below the horizontal separation must be of 2- or 3-Hour, Type 1, Construction. For open parking, either Type I or Mass Timber and Heavy Timber, Type 4, Construction is permitted.

■ The portion of the structure above the horizontal separation may be of any normally allowed Construction Type. Allowable height in stories is measured from the horizontal separation above the parking. Allowable height in feet or meters is measured from the ground plane.

A, I, B, M, and R Occupancies over Open Parking

When an S-2 Occupancy open parking garage is separated from the portion above by a (usually 2-hour) rated horizontal assembly, the structure may be treated as follows:

■ The portion of the structure below the horizontal separation may be of any normally allowed a Construction Type, but must also be at least as fire-resistant as the portion above.

■ The portion of the structure above the horizontal separation may include A, I, B, M, and R Occupancies. Any normally allowed Construction Type may be used. Allowable height, both in stories and feet or meters, is measured from the ground plane.

Open Parking over B and M Occupancies

When an S-2 Occupancy open parking garage is separated from the portion below by a 2-hour rated horizontal assembly, the structure may be treated as follows:

■ The portion of the structure below the separation may include B and M Occupancies. If of 3-hour (Type I-A) construction, it may be of any normally allowed height and area. If of any other Noncombustible Construction Type (Type I-B or Type II), it may be no more than one story above grade.

■ The Construction Type for the lower portion of the structure must also be at least as stringent as the portion above.

■ For the upper S-2 Occupancy portion of the structure, allowable height in feet or meters is measured from the ground plane.

Open Parking over Enclosed Parking

When a structure up to the first story above grade includes an S-2 enclosed parking garage separated from an S-2 open parking garage above by a (usually 2-hour) rated horizontal assembly, the structure may be treated as follows:The portion of the structure below the horizontal separation must be of Noncombustible Construction (Type I or II), and also no less fire-resistant than the portion of the structure above.

■ The portion of the structure above may be of any normally permitted construction type, with height in feet or meters and number of stories measured from the separation above the enclosed parking.

■ The proposed area of the enclosed parking divided by its allowable area plus the proposed area of the open parking divided by its allowable area cannot exceed 1.

NATIONAL BUILDING CODE OF CANADA

Mixed Occupancies

In the National Building Code of Canada, major Occupancies in a mixed-occupancy building must be separated from each other by fire-resistance rated wall and floor assemblies, with the most restrictive Construction Type, height, and area requirements of any Occupancy applied to the building as a whole. Most Occupancy separations must have 1- or 2-hour fire-resistance ratings.

High-Hazard F-1 Industrial Occupancies may not occur in the same building with A Assembly, B Care, Treatment, or Detention, or C Residential Occupancies. Medium-Hazard F-2 Industrial Occupancies may not occur in the same building with more than one C Residential Occupancy suite.

When a major Occupancy does not exceed 10% of the total area on a floor, it is not required to be separated from other Occupancies, and is not considered in the determination of height and area limits for the building. This approach cannot be applied to High-Hazard F-1 or Medium-Hazard F-2 Industrial Occupancies, regardless of area.

Mixed Construction Types

Where one Occupancy type occurs fully above or below another, each portion of the structure may meet the Construction Type requirements for that portion's Occupancy, while the more restrictive height and area requirements of either Occupancy are applied to the building as a whole. This option allows the possibility of a single building of multiple Construction Types—for example, combustible residential units above a noncombustible commercial first story. The Construction Type of the lower portion of the building must be at least as fire-resistive as the portion above.

Basement Separations

A fire separation is required between basements and floors above grade. For a single-level basement, this separation must have a fire-resistance rating of at least 45 minutes and not less than that required for floor assemblies as determined by building Construction Type requirements. For multilevel basements, this fire separation must be 2 to 3 hours, depending on the basement Occupancies. The floors within a multilevel basement cannot have less than a 45-minute fire-resistance rating.

Parking Garages and Mixed Occupancies

When a basement is used primarily as a parking garage for vehicle storage only (exclusive of vehicle servicing or fueling), it may be considered as a separate building, provided that the separation between the garage and the Occupancies above, as well as the portions of the garage walls above grade, are constructed of Noncombustible Construction with a 2-hour fire-resistance rating. In this case, the structure above the garage is subject to its own Construction Type, height, and area requirements. In some cases, the garage may also require sprinklers.

MEZZANINES

A *mezzanine* is an intermediate platform located between the floor and ceiling of a room. Under both model building codes, mezzanines of limited size are not counted toward the number of floors or the area limits of a building. However, the area of a mezzanine *is* included when calculating occupant loads and egress requirements.

International Building Code

In the International Building Code, for a mezzanine not to be counted as an additional floor level, its area may not exceed one-third of the open area of the room in which it is located. Or, mezzanines in fully sprinklered buildings of any Noncombustible Construction type may be up to one-half of the open room area. Mezzanines in certain Industrial Occupancies may be up to two-thirds of the area of the floor they are located in. Enclosed portions of the room in which mezzanines are located are not included in these calculations.

Mezzanines must remain open to the room in which they are located. Exceptions to this requirement include portions of a mezzanine with an occupant load of 10 or less; portions not exceeding 10% of the mezzanine area; mezzanines with two means of egress; and mezzanines in certain industrial or low-rise nonhazardous Occupancy buildings.

Mezzanine egress requirements are determined as for any other room or space within a building, considering, for example, the number of occupants, Occupancy type, common path of travel, travel distance, and so on. See the discussion of Exit Access, beginning on page 270, for more information.

Although mezzanine area does not contribute to building area limits, mezzanine area is included in fire area calculations. For more information about fire areas, see page 380. Mezzanines are subject to the same Construction Type requirements as the building in which they are located.

National Building Code of Canada

In the National Building Code of Canada, for a mezzanine not to be counted as an additional floor level, one of the following conditions must be met:

- The mezzanine area must not exceed 40% of the open area of the room in which it is located, with enclosed portions of the room not included in this calculation. In addition, no more than 10% of the mezzanine itself may be enclosed. and open areas of the mezzanine must have direct line-of-sight communication with the floor area below, or,
- The mezzanine area must not exceed 10% of the entire floor on which it is located or 10% of the area of a tenant space within which it is located.

When such mezzanines exceed 500 m² (5382 sq ft) in area or include B Care, Treatment, or Detention Occupancies, fire-rated construction separating the mezzanine from other floor areas, sprinklering of the building, or other protective measures, may be required.

In some cases, a mezzanine may be constructed to a lesser fire resistance than the floor on which it is located; see pages 384–385 for more information. For mezzanines with more than one level, only the first level may be omitted when determining the total number of building floors or area.

When a mezzanine occupant load does not exceed 60, and certain area and egress travel distance limits are met, egress may be provided by a single open stair leading to the floor below. See the following table. Mezzanines that do not meet these limits must provide access to one or more enclosed exits directly from the mezzanine level.

LIMITS ON MEZZANINES WITH SINGLE OPEN STAIR EGRESS

Occupancy	Maximum Mezzanine Area	Maximum Mezzanine Travel Distance[a]
A Assembly	150 m² (1615 sq ft)	15 m (49 ft)
C Residential	100 m² (1076 sq ft)	15 m (49 ft)
D Business and Personal Services	200 m² (2153 sq ft)	25 m (82 ft)
E Mercantile	150 m² (1615 sq ft)	15 m (49 ft)
F-2 Medium-Hazard Industrial	150 m² (1615 sq ft)	10 m (33 ft)
F-3 Low-Hazard Industrial	200 m² (2153 sq ft)	15 m (49 ft)

[a]Travel distance begins from the most remote point on the mezzanine. When the room containing the mezzanine requires only a single exit access doorway, travel distance is measured to the door leading from that room. If the room requires two or more exit access doorways, travel distance is measured only as far as the beginning of the stairway leading from the mezzanine.

FLOOR OPENINGS AND ATRIUMS

In both model codes, openings that create atmospheric connections between floors within a building are subject to restrictions intended to limit the rapid spread of smoke or fire between floors.

International Building Code

Floor openings are permitted in the following circumstances:

- Within dwelling units not connecting more than four floors
- In other than I-2 or I-3 Occupancies, not connecting more than two floors, and not connected to any corridor on an unsprinklered floor or to any corridor in any other Group I or R Occupancy
- In sprinklered buildings, floor openings not exceeding twice the projected area of an escalator or stairway. In B or M Occupancies, there is no limit on the number of connected floors. In other Occupancies, up to four floors may be connected.
- In parking garages, automobile ramps or elevator hoistways
- Openings protected with fire-rated shutters or doors that close automatically in the case of fire

In other than H Occupancy buildings, floor openings, called *atriums*, are permitted as follows:

- Activities on the floor level of the atrium are restricted to those with a low fire hazard, unless that area is protected by sprinklers.
- Buildings must be sprinklered throughout or unsprinklered areas must be separated from the atrium by 2-hour rated assemblies. Atrium ceilings more than 55 ft (17 m) above the atrium floor need not be sprinklered.
- Atriums connecting more than two floors must be provided with mechanical smoke control, to protect occupants from smoke and toxic gases during a fire. In some Institutional Occupancies, atriums connecting only two floors must be provided with smoke control.
- Up to three floors of a building may be open to an atrium. Additional floors must be separated from the atrium. Walls separating atriums from adjacent spaces must be 1-hour rated, and may include glass with specially configured sprinkler protection or of ¾-hour rated glass block.
- Except at its lowest level, portions of exit access travel within an atrium may not exceed 200 ft (61 m).
- No more than one-half of a building's enclosed exits may discharge through an atrium.

National Building Code of Canada

Interconnected floor spaces are permitted as follows:

- Floor openings may connect the ground floor of a building with either the floor directly above or below (but not both) if the opening size is limited as necessary for an open stairway, inclined moving walk, or escalator; the interconnected space contains only A, D, E, F-2, or F-3 Occupancies; and the building area is no more than one-half of its maximum code-permitted area.
- Floor openings are permitted as above, but with no restriction on building area, if the building is sprinklered throughout.
- In a fully sprinklered building, floor openings for escalators or inclined moving walks, not exceeding 10 m^2 (108 sq ft) in area, may connect any number of floors containing A, D, or E Occupancies.
- Floor openings may connect any two floors in a B-1 Detention Occupancy.
- Floor openings are permitted for ramps in parking garages.
- Floor openings are permitted in special industrial buildings where necessary for the flow of materials.

More extensive interconnected floor spaces are also permitted when meeting all of the following requirements:

- The building is fully sprinklered.
- Mechanical smoke control is provided.
- The quantity of combustible contents located in interconnected floor spaces is limited.
- Exits opening into interconnected floor spaces are protected by vestibules.
- Exits serving interconnected floors must allow the simultaneous evacuation of occupants from all interconnected floors. This means that either exit stair capacity is increased to provide refuge for occupants, or *protected floor spaces* adjacent to exits are provided.
- Elevator shafts, opening into interconnected floors and additional floors above, must be protected by vestibules, either at the interconnected floors or at the floors above.
- Sleeping rooms in B-2 Occupancies are not located within interconnected floor spaces.
- Occupancies not permitted within interconnected floor space are separated from the interconnected floor space by walls with a fire-resistance rating equal to that of the floor.

FIRE SPRINKLERS

In addition to the sprinkler requirements incorporated into the height and area tables beginning on pages 394 and 450, both model building codes require sprinklers in a variety of other circumstances.

In the International Building Code:

■ Most buildings with floors more than 55 ft (16.8 m) above the lowest ground level and with 30 or more occupants must be sprinklered throughout (excluding open parking garages and F-2 Low-Hazard Industrial Occupancy buildings). Buildings with occupied floors more than 75 ft (23 m) above the lowest ground level must meet additional fire safety requirements. See page 297 for more information.

■ Most buildings with occupied floors more than 30 ft (9.1 m) below the lowest grade must have all exit levels and below-grade levels sprinklered. For more information on underground building requirements, see pages 297–298.

■ Stories above or below grade exceeding 1500 sq ft (139 m^2) in area without openings to the exterior, or with openings limited in size or extent, must be sprinklered.

In the National Building Code of Canada:

■ *High buildings* must be sprinklered throughout. See page 298 for information on high building requirements.

■ Where a story is required to be sprinklered throughout, all stories below that story (including both above- and below-ground stories) must also be sprinklered.

■ Normally, all basements levels must be sprinklered. However, if the ground-level floor of a building is not required to be sprinklered, the following exceptions may be applied: Basement levels may remain unsprinklered if they are subdivided by fire separations into compartments not greater than 600 m^2 (6460 sq ft) in area. Or a first story below grade may remain unsprinklered if it contains only Residential Occupancies and has direct access from a public street in the form of doors, windows, or other acceptable openings.

FIRE AREAS AND FIRE COMPARTMENTS

In the International Building Code, fire-resistance rated walls and floor/ceiling assemblies may be used to subdivide portions of a building into so-called *fire areas*. Fire area size is one factor in determining when fire sprinklers are required for a particular Occupancy. In some circumstances, limiting the size of a fire area can eliminate the need for sprinklering. For this code, fire area requirements are included in the text accompanying the height and area tables beginning on page 394.

Fire area size is determined by measuring the floor area surrounded by exterior walls or interior fire-rated wall and floor assemblies. For example, in a single-story building with the interior undivided, the fire area is calculated as the entire floor area of the building. In a multistory building, where interior walls and floor/ceiling assemblies are all unrated, the fire area is calculated as the sum of the areas of all floors. On the other hand, in this second example, if floor/ceiling assemblies are constructed with sufficient fire resistance, each floor may be considered as a separate, smaller fire area. The floor area of mezzanines is included in fire area calculations, as is the combined area of floors connected by unprotected openings.

Even when a fire area requirement applies only to one particular Occupancy, fire area is measured including all areas that are not separated by rated assemblies. For example, consider a single-story office building, 15,000 sq ft in area, including a 1000-sq-ft A-3 Assembly Occupancy space and the remainder B Occupancy. According to the information provided with the table on pages 400–401, A-3 Occupancies with a fire area greater than 12,000 sq ft must be sprinklered. In this example, if the assembly and business areas are not separated, the fire area is the area of the entire floor, 15,000 sq ft, and the entire floor must be sprinklered. Alternatively, if adequately rated wall assemblies are used to separate the assembly and business areas, the fire area of the assembly space is only 1000 sq ft, and sprinklers are no longer required.

Fire-resistance rating requirements for separations between fire areas range from 1 to 4 hours, depending on the type of Occupancy involved. For preliminary purposes, a 2-hour rating may be assumed for nonhazardous Occupancies.

The National Building Code of Canada defines *fire compartments* as areas surrounded by fire-resistance rated wall and floor assemblies. Fire compartment size can be a factor, for example, in the limits placed on the presence of combustible finish materials in buildings of Noncombustible Construction Types or the maximum area of openings in fire separation walls or exterior walls. Fire compartment size may also affect requirements for sprinklers in certain occupancy conditions.

EXTERIOR WALLS

Where the distance between buildings is small, the fire-resistance rating of exterior walls sometimes must be increased to reduce the risk of fire spreading between them. In the International Building Code, proximity of buildings is measured as *fire separation distance*, and in the National Building Code of Canada as *limiting distance*. In both codes, this distance is measured as one of the following:

- For abutting properties, from the face of a building to the shared property line
- For properties abutting a public way, from the face of a building to the center of the street or way
- For two buildings on the same property, from the face of either building to a single, arbitrary line established between them. The line need not be equidistant between the two buildings.

These distances are always measured perpendicular to the face of the building. The required ratings are applied to exterior walls only when they will result in an increase in the fire-resistance requirements of the building's Construction Type. They cannot be applied to reduce Construction Type requirements.

In the International Building Code, fire-resistance rating requirements vary with fire separation distance, Occupancy, and Construction Type. Excluding High-Hazard Occupancies, minimum ratings for exterior walls range from 1 to 2 hours for walls with a fire separation distance of less than 10 ft (3.0 m), and from 0 to 1 hours for walls with a fire separation distance of less than 30 ft (9.1 m).

In the National Building Code of Canada, exterior wall fire-resistance rating requirements vary with limiting distance, Occupancy, area of the exterior wall, and the presence of sprinklers. For fully sprinklered buildings, minimum ratings from 45 minutes to 2 hours are required for walls with limiting distance ranging from 1.2 to 15 m (3 ft 11 in. to 49 ft). For buildings that are not fully sprinklered, the same range of minimum ratings applies with limiting distance ranging from 9 to 70 m (30 to 230 ft). At small limiting distances, the code may also restrict exterior walls to only Noncombustible Construction.

In both model codes, as fire separation or limiting distance decreases, the extent of windows, doors, and other unprotected openings permitted in exterior walls is also reduced. In the International Building Code, no such openings are permitted in walls with a fire separation distance of less than 3 to 5 ft (0.9 to 1.5 m), and in the National Building Code of Canada, a limiting distance of less than 1.2 m (3 ft 11 in.).

FIRE WALLS

Fire walls are used to divide structures into two or more parts, such that the construction on either side of the wall may be considered a separate building for the purposes of determining its Construction Type and allowable height and area. In this way, a building of virtually any horizontal extent can be built, so long as it is subdivided by fire walls into self-contained parts that individually comply with code limits.

Fire walls require a fire-resistance rating of 2 to 4 hours, depending on building occupancy, and must completely separate the structures on either side. They must be constructed either as two separate walls, each independently supported by the structures on opposite sides, or as one wall that can remain standing in the event of a structural collapse on either side. The National Building Code of Canada also permits a single fire wall to be supported by a noncombustible structure when that structure has a fire-resistance rating at least as great as that required for the wall.

The International Building Code requires fire walls to be of Noncombustible Construction, unless separating solely Type V Wood Light Frame structures on both sides. In the National Building Code of Canada, fire walls must be of Noncombustible Construction, and when four-hour-rated, constructed of only masonry or concrete.

Depending on the fire resistance of the building's exterior construction, fire walls may be required to project beyond exterior walls and/or roofs a distance ranging from 6 to 36 in. (150 to 900 mm), to limit the chance of fire jumping from one side of the wall to the other. Where exterior walls and roofs have sufficient fire resistance themselves, fire walls may be permitted to terminate at these boundaries without projection. For the same reason, openings in exterior walls or roofs within certain distances of fire walls may be restricted.

Within fire walls themselves, openings, most commonly for doors, must be fire rated. Each opening must meet specified size limits, and the area of all openings taken together must not exceed 25% of the wall's total area.

INTERNATIONAL BUILDING CODE

This section summarizes the fire-resistance rating and construction requirements for Construction Types in the International Building Code. Once you have determined an appropriate Construction Type for a project, based on the height and area tables on pages 396–449, use this section to relate the Construction Type to complete systems of construction. The table on these two facing pages consolidates and simplifies the fire-resistance requirements for each Construction Type. The pages following this chart define each Construction Type in terms of specific structural systems, materials, and minimum thicknesses of components necessary to meet the required fire-resistance rating. The values in the table below may be modified as follows:

Structure Supporting Roofs Only: In 3-Hour and 2-Hour (Type I) Construction, fire-resistance requirements for the structural frame and interior bearing walls supporting roofs only may be reduced by 1 hour. Roof construction and exterior bearing wall fire-resistance requirements are not reduced.

Roof Construction: Roof structures 20 ft (6 m) or more above the floor below may be unprotected except in F-1, H, M, and S-1 Occupancies. In all Occupancies, Heavy Timber Construction is permitted wherever a roof structure with a fire-resistance rating of 1 hour or less is permitted.

Exterior Bearing Walls: In addition to the requirements indicated in the table on these two facing pages, see page 381 for information regarding protection of exterior walls when in close proximity to other buildings.

Exterior Walls in Type III and IV Construction: In Types III and IV Construction, exterior walls must be of noncombustible materials. Or, in some instances, mass timber materials or fire-retardant-treated wood framing and sheathing may be used.

Enclosures for Corridors and Exits: For more information about enclosures for corridors, see page 273; for exits, see page 280.

Mall Tenant Spaces: Individual tenant spaces in covered mall buildings must be separated from each other (but not from the mall

INTERNATIONAL BUILDING CODE FIRE-RESISTANCE RATING REQUIREMENTS

	Noncombustible			
CONSTRUCTION TYPE	**3-Hour (page 386)**	**2-Hour (page 386)**	**1-Hour (page 387)**	**Unprotected (page 387)**
INTERNATIONAL BUILDING CODE NOMENCLATURE	**Type I-A**	**Type II-A**	**Type II-A**	**Type II-B**
STRUCTURAL FRAME INCLUDING COLUMNS, GIRDERS, TRUSSES	3	2	1	0
EXTERIOR BEARING WALLS	3	2	1	0
INTERIOR BEARING WALLS	3	2	1	0
FLOOR CONSTRUCTION	2	2	1	0
ROOF CONSTRUCTION	½–1	1	1	0
PARTY WALLS AND FIRE WALLS	2–4	2–4	2–4	2–4
EXIT STAIR, EXIT PASSAGEWAY, AND SHAFT ENCLOSURES	2	2	2-hour connecting 4 stories or more 1-hour connecting fewer than 4 stories	
EXIT ACCESS CORRIDORS (PAGE 273)	0–1	0–1	0–1	0–1
DWELLING AND SLEEPING UNIT SEPARATIONS	1	1	1	½–1
OTHER NONBEARING PARTITIONS	0	0	0	0

space) by wall and floor assemblies with a 1-hour fire-resistance rating.

Dwelling Unit and Sleeping Unit Separations: Walls separating dwelling units or sleeping units in I-1 Residential Care, R-1 Hotel and Motel, R-2 Multifamily, R-3 Miscellaneous Residential, and R-4 Residential Assisted Living Occupancies must be separated from other such units and from other Occupancies by wall and floor assemblies with a fire-resistance rating of between ½- and 1-hour, depending on Construction Type and the presence of sprinklers.

Other Fire-Resistance Rated Partition Types: For occupancy separations, see page 374; for fire area separations, see page 380.

Tall Buildings: For most buildings with occupied floors more than 75 ft (23 m) above grade but with roofs not higher than 420 ft (128 m), and equipped with enhanced sprinkler systems, Construction Type and rated assembly requirements may be adjusted as follows:

- Buildings of Type I-B Construction may be built to the height and area limits of Type I-A Construction, except that columns supporting floors must be built to the requirements of Type I-A Construction.
- In other than Group F-1, M, and S-1 Occupancies, buildings of Type II-A Construction may be built to the height and area limits of Type I-B Construction.
- Shafts for other than exits and elevators may be enclosed with 1-hour fire-resistance rated construction when the interiors of the shafts themselves are protected with an automatic sprinkler system.

In tall buildings with a high level of life-safety risk Occupancies or with roofs higher than 420 ft (128 m), exit and elevator shaft walls must be constructed of concrete, masonry, impact-resistant gypsum wallboard, or other materials meeting special impact-resistance requirements. Examples of Occupancies included in this requirement may include various Assembly, Educational, and Institutional, and other Occupancies depending also on the number of occupants.

These provisions do not apply to open parking garages, airport traffic control towers, outdoor sports arenas, and some unusually tall low- and medium-hazard industrial buildings. For special egress system and smoke control requirements in tall buildings, see High-Rise Building Egress, page 297.

		Mixed Combustible/Non-Combustible					
Ordinary		**Mass Timber**			**Mill**	**Wood Light Frame**	
1-Hour (page 387)	**Unprotected (page 387)**	**(page 388)**			**Heavy Timber (page 388)**	**1-Hour (page 391)**	**Unprotected (page 391)**
Type III-A	**Type III-B**	**Type IV-A**	**Type IV-B**	**Type IV-C**	**Type IV-HT**	**Type V-A**	**Type V-B**
1	0	3	2	2	Heavy Timber	1	0
2	2	3	2	2	2	1	0
1	0	3	2	2	1 or Heavy Timber	1	0
1	0	2	2	2	Heavy Timber	1	0
1	0	½–1	1	1	Heavy Timber	1	0
2–4	2–4	2–4	2–4	2–4	2–4	2–4	2–4
2-hour connecting 4 stories or more 1-hour connecting fewer than 4 stories							
0–1	0–1	0–1	0–1	0–1	0–1	0–1	0–1
1	½–1	1	1	1	1	1	½–1
0	0	0	0	0	0	0	0

NATIONAL BUILDING CODE OF CANADA

This section summarizes the fire-resistance rating and construction requirements for Construction Types in the National Building Code of Canada. Once you have determined an appropriate Construction Type for a project based on the height and area tables on pages 452–479, use this section to relate this information to systems of construction. The table on these two facing pages consolidates and simplifies the fire-resistance requirements for each Construction Type. The pages following this chart define each Construction Type in terms of specific structural systems, materials, and minimum thicknesses of components necessary to meet the required minimum fire-resistance rating. The values in the following table may be modified as follows:

- **Loadbearing Columns, Walls, and Arches:** In general, loadbearing elements must have a fire-resistance rating not less than that of the floor, mezzanine, or roof supported by those elements. Where such floors, mezzanines, or roofs are required to be noncombustible, the supporting elements must be noncombustible as well.
- **Exterior Bearing Walls:** In addition to the requirements indicated in the table on these two facing pages, see page 381 for information regarding protection of exterior walls in close proximity to other buildings.

NATIONAL BUILDING CODE OF CANADA FIRE-RESISTANCE RATING REQUIREMENTS

	Noncombustible			
CONSTRUCTION TYPE	**2-Hour (page 386)**	**1-Hour (page 386)**	**¾-Hour (page 387)**	**Unprotected (page 387)**
LOADBEARING COLUMNS, WALLS, AND ARCHES	Not less than that required for the floor, mezzanine, or roof supported			
FLOOR CONSTRUCTION	2	2	1	0
MEZZANINES	1	1	0	0
ROOF CONSTRUCTION	0	0–1	0	0
PARTY WALLS AND FIRE WALLS	2–4	2–4	2–4	2–4
EXIT STAIR, EXIT PASSAGEWAY, AND SHAFT ENCLOSURES	2	2	2-hour connecting 4 stories or more 1-hour connecting fewer than 4 stories	
EXIT ACCESS CORRIDORS (PAGE 273)	0–1	0–1	0–1	0–1
COMMERCIAL TENANT SEPARATIONS	0–1	0–1	0–1	0–1
DWELLING UNIT AND GUEST ROOM SEPARATIONS	¾–1	¾–1	¾–1	¾–1
OTHER NONBEARING PARTITIONS	0 (noncombustible)			

■ **Mass Timber Construction:** For more information about this construction type, see page 390.

■ **Heavy Timber Construction:** Heavy Timber Construction is an acceptable substitute wherever ¾-Hour or Unprotected Combustible Construction is permitted.

■ **Heavy Timber Roofs:** In any sprinklered building not taller than two stories, the roof assembly and structural members supporting it immediately below may be of Heavy Timber Construction.

■ **Roofs:** An occupied roof must be constructed to the same level of fire resistance as a floor.

■ **Long-Span Roofs:** Long-span roofs over arenas, sports facilities, and other such spaces are not required to have a fire-resistance rating when not less than 6 m (20 ft) above the floor and supporting normal roof loads only.

■ **Corridor Enclosures:** For more information on enclosure requirements for exits and corridors, see pages 273 and 280.

■ **Other Fire-Resistance Rated Partition Types:** For occupancy separations, see page 374.

Combustible				
Heavy Timber (page 390)	**1-Hour (page 391)**	**¾-Hour (page 391)**	**Unprotected (page 391)**	**CONSTRUCTION TYPE**
Heavy Timber	Not less than that required for the floor, mezzanine, or roof supported			**LOADBEARING COLUMNS, WALLS, AND ARCHES**
Heavy Timber	1	¾	0	**FLOOR CONSTRUCTION**
Heavy Timber	1	0–¾	0	**MEZZANINES**
Heavy Timber	0–1	0–¾	0	**ROOF CONSTRUCTION**
2–4	2–4	2–4	2–4	**PARTY WALLS AND FIRE WALLS**
2-hour connecting 4 stories or more 1-hour connecting fewer than 4 stories				**EXIT STAIR, EXIT PASSAGEWAY, AND SHAFT ENCLOSURES**
0–1	0–1	0–1	0–1	**EXIT ACCESS CORRIDORS (PAGE 273)**
0–1	0–1	0–1	0–1	**COMMERCIAL TENANT SEPARATIONS**
¾–1	¾–1	¾–1	¾–1	**DWELLING UNIT AND GUEST ROOM SEPARATIONS**
0	0	0	0	**OTHER NONBEARING PARTITIONS**

NONCOMBUSTIBLE CONSTRUCTION

Noncombustible structures are constructed principally of steel, concrete, and masonry. In both model codes, the use of wood is mostly limited to minor applications such as blocking for attachments within walls or roofs, and so forth. The International Building Code allows fire-retardant treated wood to be used in nonbearing interior partitions with fire-resistance ratings of 2 hours or less, in nonbearing exterior walls where no rating is required, and in some roof structures. The National Building Code of Canada allows wood construction in the exterior walls of noncombustible structures not more than 3 stories in height, where the building is fully sprinklered, and the wall meets certain fire-test criteria or is protected on the exterior by masonry or concrete cladding.

3-HOUR NONCOMBUSTIBLE CONSTRUCTION

Three-Hour Noncombustible Construction requires a fire-resistance rating of 3 hours for columns and bearing walls and 2 hours for floor construction.

■ **Structural Steel** members must be protected to these values with applied fire-resistive materials that typically range in thickness from approximately 1 to 3 in. (25–75 mm).

■ **Light Gauge Steel** wall framing can be assumed to achieve a 3-hour fire-resistance rating with the application of three layers of ½-in. (13-mm) Type X gypsum wallboard to both sides of the framing. Floor framing can achieve a 2-hour rating with two layers of ⅝-in. (16-mm) Type X gypsum wallboard applied to the underside of framing supporting cement panels or a concrete deck.

■ **Reinforced Concrete** columns must be at least 12 in. (300 mm) in dimension, and loadbearing walls must be at least 6 in. (150 mm) thick. Floor slabs must be at least 5 in. (125 mm) thick. Concrete one-way and two-way joist systems with slabs thinner than 5 in. (125 mm) between joists require protection with applied fireproofing materials.

■ **Posttensioned Concrete** floor slabs must be at least 5 in. (125 mm) thick.

■ **Precast Concrete** columns must be at least 12 in. (300 mm) in dimension, and beams must be at least 7 in. (175 mm) wide. Loadbearing wall panels must be at least 6 (150 mm) thick. Solid slabs may not be less than 5 in. (125 mm) thick. Hollow-core slabs must be at least 8 in. (200 mm) deep and may be used without a topping. Double and single tees require applied fireproofing materials or a 3¼ in.-(85 mm-) thick concrete topping.

■ **Brick Masonry** loadbearing walls must be at least 6 in. (150 mm) thick. Vaults and domes must be at least 8 in. (200 mm) deep, with a rise not less than one-twelfth the span.

■ **Concrete Masonry** columns must be at least 12 in. (300 mm) in dimension, and loadbearing walls must be at least 8 in. (200 mm) thick. Depending on the composition and design of the masonry unit, applied plaster or stucco facings may also be required.

2-HOUR NONCOMBUSTIBLE CONSTRUCTION

Two-Hour Noncombustible Construction requires a fire-resistance rating of 2 hours for columns, bearing walls, and floor construction.

■ **Structural Steel** members must be protected to these values with applied fireproofing materials that typically range in thickness from approximately 1 to 2 in. (25–50 mm).

■ **Light Gauge Steel** framing can be assumed to achieve a 2-hour fire-resistance rating with the application of two layers of ⅝-in. (16-mm) Type X gypsum wallboard to both sides of wall framing or to the underside of floor framing supporting a concrete deck.

■ **Reinforced Concrete** columns must be at least 10 in. (250 mm) in dimension, and loadbearing walls must be at least 5 in. (125 mm) thick. Floor slabs must be at least 5 in. (125 mm) thick. Concrete one-way and two-way joist systems with slabs thinner than 5 in. (125 mm) between joists require protection with applied fireproofing materials.

■ **Posttensioned Concrete** floor slabs must be at least 5 in. (125 mm) thick.

■ **Precast Concrete** columns must be at least 10 in. (250 mm) in dimension, and beams must be at least 7 in. (175 mm) wide. Loadbearing wall panels must be at least 5 in. (120 mm) thick. Solid slabs may not be less than 5 in. (120 mm) thick. Hollow-core slabs must be at least 8 in. (200 mm) deep and may be used without a topping. Double and single tees require applied fireproofing materials or a 3¼ in.-(85 mm-) thick concrete topping.

■ **Brick Masonry** loadbearing columns must be at least 12 in. (300 mm) in dimension, and walls must be at least 6 in. (150 mm) thick. Vaults and domes must be at least 8 in. (200 mm) deep, with a rise not less than one-twelfth the span.

■ **Concrete Masonry** columns must be at least 10 in. (250 mm) in dimension, and loadbearing walls must be at least 8 in. (200 mm) thick. Depending on the composition and design of the masonry unit, applied plaster or stucco facings may also be required.

1-HOUR NONCOMBUSTIBLE CONSTRUCTION

One-Hour Noncombustible Construction requires a fire-resistance rating of 1 hour for columns, bearing walls, and floor construction.

■ **Structural Steel** members must be protected to these values with applied fireproofing materials typically 1 in. (25 mm) or less in approximate thickness.

■ **Light Gauge Steel** framing can be assumed to achieve a 1-hour fire-resistance rating with the application of one layer of ⅝-in. (16-mm) Type X gypsum wallboard to both sides of wall framing or to the underside of floor framing supporting a concrete deck.

■ **Reinforced Concrete** columns must be at least 8 in. (200 mm) in dimension, and loadbearing walls must be at least 4 in. (100 mm) thick. Floor slabs must be at least 3½ in. (90 mm) thick. Concrete one-way and two-way joist systems with slabs less than 3½ in. (90 mm) thick require protection with applied fireproofing materials.

■ **Posttensioned Concrete** floor slabs must be at least 3½ in. (90 mm) thick.

■ **Precast Concrete** columns must be at least 10 in. (250 mm) in dimension, and beams must be at least 4 in. (100 mm) wide. Loadbearing wall panels must be at least 3½ in. (90 mm) thick. Solid slabs may not be less than 3½ in. (90 mm) thick. Hollow-core slabs must be at least 8 in. (200 mm) deep and may be used without a topping. Double and single tees require applied fireproofing materials or a concrete topping 1¾ in. (45 mm) thick.

■ **Brick Masonry** columns must be at least 8 in. (200 mm) in dimension, and loadbearing walls must be at least 6 in. (150 mm) thick. Vaults and domes must be at least 4 in. (100 mm) deep, with a rise not less than one-twelfth the span.

■ **Concrete Masonry** columns must be at least 8 in. (200 mm) in dimension, and loadbearing walls must be at least 8 in. (200 mm) thick. Depending on the composition and design of the masonry unit, applied plaster or stucco facings may also be required.

¾-HOUR NONCOMBUSTIBLE CONSTRUCTION

Three-Quarter-Hour Noncombustible Construction requires a fire-resistance rating of 45 minutes for columns, bearing walls, and floors. This Construction Type is unique to the National Building Code of Canada. In practice, it is most commonly applied to lightweight steel framing systems. For preliminary design purposes, the information provided on this page for 1-Hour Noncombustible Construction may be used to achieve this system's required levels of fire resistance.

UNPROTECTED NONCOMBUSTIBLE CONSTRUCTION

Unprotected Noncombustible Construction has no fire-resistive requirements for its structural elements other than that they be of noncombustible materials (or unless other fire-resistance requirements apply, such as for exit enclosures, occupancy separations, etc.).

ORDINARY CONSTRUCTION

Ordinary Construction is a system with historical roots in North American early-industrial-era factory building. In the International Building Code, it is referred to as Type III Construction.

Exterior Walls must have a fire-resistance rating of at least 2 hours and be of noncombustible construction or fire-retardant treated wood framing and sheathing. However, if some other code requirement dictates a rating greater than 2 hours, only noncombustible construction may be used.

The **Interior Structure** may be constructed of wood light framing. For *1-Hour Ordinary Construction*, use the requirements for 1-Hour Wood Light Frame Construction listed on the following pages. For *Unprotected Ordinary Construction*, use the requirements for Unprotected Wood Light Frame Construction.

MASS TIMBER AND HEAVY TIMBER CONSTRUCTION

Mass Timber and Heavy Timber Construction depend for their fire-resistant properties on wood members of sufficient thickness such that they are slow to catch fire and burn. When minimum size requirements are met, solid wood, glue-laminated members, structural composite lumber, cross-laminated timber (CLT), and other large-format wood products may be used.

International Building Code

In the International Building Code, mass timber and heavy timber members must meet the minimum size requirements in the facing page table.

In this code, *Heavy Timber Construction* is labeled as Type IV-HT. In addition to meeting minimum wood member size requirements, construction of this type must comply with the following:

- Exterior walls may be of noncombustible construction (traditionally called *Mill Construction*), fire-retardant treated wood light framing, or CLT. Heavy timber framing that is part of CLT construction, and with at least a 2-hour fire-resistance rating, is also permitted. CLT and heavy timber framing must be covered on the exterior side with ½ in. (12 mm) gypsum board, fire-retardant treated plywood, or other noncombustible material.
- Where exterior walls require a fire-resistance rating greater than 2 hours, only noncombustible materials are permitted.

Mass Timber Construction is labeled as Types IV-A, IV-B, and IV-C. In addition to meeting the minimum wood member size requirements, components must meet the prescribed fire-resistance ratings listed in the table on page 383. In Type IV-C construction, all of the required fire-resistance can be derived from the wood members themselves, or some or all of the protection can be provided by applied fire-resistive materials. In Types IV-A and IV-B construction, at least two-thirds of the required fire protection must come from applied fire-resistive materials, and one-third or less may be derived from the wood members themselves. See the following for examples.

In Type IV-A construction:

- Exterior walls must be of noncombustible construction with at least a 40-minute fire-resistance rating.
- Where a 3-hour fire-resistance rating is required, wood components must receive at least 120 minutes of applied protection, such as for example, with three layers of ⅝ in. (16 mm) Type X gypsum wallboard. Up to 60 minutes of protection can derive from the wood members.
- Other interior wood components must be protected with applied fire-resistive materials providing at least 80 minutes of protection, such as for example, two layers of ⅝ in. (16 mm) Type X gypsum board.
- Mass timber floors must be covered with at least 1 in. (25 mm) of noncombustible material, such as gypsum or concrete topping.

In Type IV-B construction:

- Wood components in exterior walls must be covered on the exterior side with noncombustible materials providing at least a 40-minute fire-resistance rating, such as for example, with one layer of ⅝ in. (16 mm) gypsum sheathing.
- With limited exceptions, interior wood components must receive at least 80 minutes of applied protection, such as for example, with two layers of ⅝ in. (16 mm) Type X gypsum wallboard.
- Up to 20% of some ceiling areas or 40% of some wall areas may be exempted from the requirements for applied protection. Additionally, columns and beams that are not parts of ceilings or walls may derive up to all of their required fire-resistance from the wood members without applied protection.
- Mass timber floors must be covered with at least 1 in. (25 mm) of noncombustible material, such as gypsum or concrete topping.

In Type IV-C construction:

- Wood components in exterior walls must be covered on the exterior side with noncombustible materials providing at least a 40-minute fire-resistance rating, such as for example, with one layer of ⅝ in. (16 mm) gypsum sheathing.
- Interior wood components may derive up to all of their required fire-resistance from the wood members themselves.

In both Heavy Timber and Mass Timber Construction, concealed combustible spaces are restricted, and where permitted, must be protected against the possibility of supporting concealed fire with noncombustible fire blocking materials, fire sprinklering, or other suitable methods.

For information about the sizing of Mass Timber and Heavy Timber components, see pages 66–79.

INTERNATIONAL BUILDING CODE MINIMUM WOOD MEMBER SIZES FOR MASS TIMBER AND HEAVY TIMBER CONSTRUCTION

	Minimum Size (width × depth)		
Member Type	**Solid Wood**	**Glue-Laminated Timber (Actual Size)**	**Structural Composite Lumber (Actual Size)**
Columns, arches, and trusses supporting floors	8 × 8 nominal 7½ × 7½ in. (191 ×191 mm) actual size	6¾ × 8¼ in. (171 × 210 mm)	7 × 7½ in. (178 × 191 mm)
Columns supporting roofs	6 × 8 nominal 5½ × 7½ in. (140 × 191 mm) actual size	5 × 8¼ in. (127 × 210 mm)	5¼ × 7½ in. (133 × 191 mm)
Beams supporting floors	6 × 10 nominal 5½ × 9½ in. (140 × 241 mm) actual size	5 × 10½ in. (127 × 267 mm)	5¼ × 9½ in. (133 × 241 mm)
Beams and trusses supporting roofs	4 × 6 nominal 3½ × 5½ in. (89 × 140 mm) actual size	3 × 6 ⅞ in. (76 × 175 mm)	3½ × 5½ in. (89 × 140 mm)
Arches supporting roofs	When springing from the floor below, lower half:		
	6 × 8 nominal 5½ × 7½ in. (140 × 191 mm) actual size	5 × 8¼ in. (127 × 210 mm)	5¼ × 7½ in. (133 × 191 mm)
	When springing from the floor below, upper half:		
	6 × 6 nominal 5½ × 5½ in. (140 × 140 mm) actual size	5 × 6 in. (127 × 140 mm)	5¼ × 5½ in. (133 × 140 mm)
	When springing from the tops of walls:		
	4 × 6 nominal 3½ × 5½ in. (89 × 140 mm) actual size	3 × 6 ⅞ in. (76 × 175 mm)	3½ × 5½ in. (89 × 140 mm)
Interior walls	4 in. (102 mm) laminated solid wood or CLT Or, two layers of 1-inch (25 mm) matched boards		
CLT exterior walls	Mass Timber: 6 in. (152 mm) CLT Heavy Timber: 4 in. (102 mm) CLT		
CLT floors	4 in. (102 mm) thick		
Other floor decks	3 in. nominal (64 mm) solid or glue-laminated wood structural decking or 4 in. nominal (102 mm) members laid on edge, overlaid with 1 in. nominal (19 mm) finish wood flooring or ½ in. (13 mm) plywood or other wood panels		
CLT roofs	3 in. (76 mm) thick		
Other roof decks	2 in. nominal (38 mm) solid or glue-laminated wood structural decking, 3 in. nominal (64 mm) members laid on edge, or 1 ⅛-in. (28-mm) structural wood panels		Built-up members
Individual members in built-up heavy timber roof beams and trusses of any type may be as small as 3 in. (2½ in. or 64 mm actual size) in width.			

National Building Code of Canada

In the National Building Code of Canada, wood members of *Heavy Timber Construction* must meet the minimum size requirements listed in the table to the right.

In the National Building Code of Canada 2020 (published in 2022), mass timber construction is referred to as *Encapsulated Mass Timber Construction*. Minimum permitted sizes for mass timber members are listed in the second table to the right. Additional requirements for this type of construction include:

- Most mass timber elements must achieve a 2-hour fire-resistance rating. At least 50 minutes of protection must be provided by applied fire-resistive materials, such as, for example, 38 mm (1½ in.) of concrete topping or two layers of 12.7 mm (½ in.) Type X gypsum board.
- In some circumstances, between 10% and 35% of wall or ceiling elements may remain exposed within a suite.
- Concealed combustible spaces are restricted and, where permitted, must be protected against the possibility of supporting concealed fire with noncombustible fire blocking materials, fire sprinklering, or other suitable method.

Encapsulated Mass Timber Construction may be used for fully sprinklered buildings up to 12 stories and 42 m (138 ft) in height, with Group C major occupancies up to 6000 m^2 (64,600 sf) in total area and Group D major occupancies up to 7200 m^2 (77,500 sf) in area. In some circumstances some Group A, E, F, and storage garage occupancies, with lesser maximum heights, are also permitted.

NATIONAL BUILDING CODE OF CANADA MINIMUM MEMBER SIZES FOR HEAVY TIMBER CONSTRUCTION

	Minimum Size (width × depth)	
Member Type	**Solid Wood (Actual Size)**	**Glue-Laminated Timber (Actual Size)**
Columns supporting floors	191 ×191 mm (7½ × 7½ in.)	175 × 190 mm (6 ⅞ × 7½ in.)
Columns supporting roofs	140 × 191 mm (5½ × 7½ in.)	130 × 190 mm (5 ⅛ × 7½ in.)
Beams, trusses, and arches supporting floors	140 × 241 mm or 191 × 191 mm (5½ × 9½ or 7½ × 7½ in.)	130 × 228 or 175 × 190 mm (5 ⅛ × 9 or 6 ⅞ × 7½ in.)
Beams and trusses supporting roofs	89 × 140 mm (3½ × 5½ in.)	80 × 152 mm (3 ⅛ × 6 in.)
Arches supporting roofs	When springing from the floor below:	
	140 ×140 mm (5½ × 5½ in.)	130 × 152 mm (5 ⅛ × 6 in.)
	When springing from tops of walls:	
	89 × 140 mm (3½ × 5½ in.)	80 × 152 mm (3 ⅛ × 6 in.)
Floor decks	64 mm (2½ in.) wood structural decking or 38 mm wide × 89 mm deep (1½ × 3½ in.) wood members laid on edge, overlaid with 19 mm (¾ in.) thick wood flooring or 13 mm (½ in.) plywood or other wood panels	
Roof decks	38 mm (1½ in.) wood structural decking, or 38 mm wide × 64 mm deep (1½ × 2½ in.) wood members laid on edge, or 28 mm (1 ⅛-in) structural wood panels	

NATIONAL BUILDING CODE OF CANADA 2020 MINIMUM SIZES FOR ENCAPSULATED MASS TIMBER MEMBERS

Member Type	**Minimum Size (Actual Size)**
Beams, columns, and arches	4-sided fire exposure: 224 × 224 mm (8 ⅞ in.) 2- or 3- sided fire exposure: 192 × 192 mm (7 ⅝ × 7 ⅝ in.)
Floors and roofs	1-sided fire exposure: 96 mm (3¾ in.)
Walls	2-sided fire exposure and requiring a fire-resistance rating: 192 mm (7 ⅝ in.) 1-sided fire exposure fire separation or exterior walls: 96 mm (3¾ in.)

For information about the sizing of Mass Timber and Heavy Timber components, see pages 66–79.

Even though some text has been removed from this page, keep the page break after this paragraph.

1-HOUR WOOD LIGHT FRAME/COMBUSTIBLE CONSTRUCTION

Floors, walls, and roofs of Wood Light Frame/Combustible Construction are framed with wood members not less than 2 in. in nominal thickness (1½ in. or 38 mm actual size). These members are usually spaced at center-to-center distances of either 16 or 24 in. (400 or 600 mm) and covered with any of a variety of sheathing and finish materials.

In 1-Hour Wood Light Frame/Combustible Construction, load-bearing walls and floors must have 1-hour fire-resistance ratings.

■ **Wood Light Framing** can be assumed to achieve a 1-hour fire-resistance rating with the application of one layer of ⅝-in. (16-mm) Type X gypsum wallboard to both sides of wall framing, or one to two layers of Type X gypsum wallboard to the underside of floor framing supporting wood or concrete decks (see pages 58–65).

¾-HOUR WOOD LIGHT FRAME/COMBUSTIBLE CONSTRUCTION

Three-Quarter-Hour Combustible Construction, unique to the National Building Code of Canada, requires a fire-resistance rating of 45 minutes for combustible floors, columns, and bearing walls. This code also permits Heavy Timber Construction as a substitute wherever ¾-Hour Combustible Construction is required.

For preliminary design purposes, the information provided on this page for 1-Hour Wood Light Frame/Combustible Construction may be used to achieve this system's required levels of fire resistance. Any noncombustible Construction Type with a 1-hour or greater fire-resistance rating is also permitted.

UNPROTECTED WOOD LIGHT FRAME/ COMBUSTIBLE CONSTRUCTION

Unprotected Wood Light Frame/Combustible Construction permits construction with any materials, both combustible and noncombustible, without added fire protection (unless other fire-resistance requirements apply, such as for exit enclosures, occupancy separations, etc.). Buildings of this type are most commonly constructed with Wood Light Framing (see pages 58–65).

2 HEIGHT AND AREA TABLES

This chapter allows you to determine the allowable height and area for your building, depending on the applicable model building code, occupancies within your building, and the selected Construction Type.

HOW TO USE THE TABLES OF HEIGHT AND AREA LIMITATIONS FOR THE INTERNATIONAL BUILDING CODE

1. Be sure you are consulting the tables for the proper building code. If you are not sure which code you are working under, see pages 6 and 13.

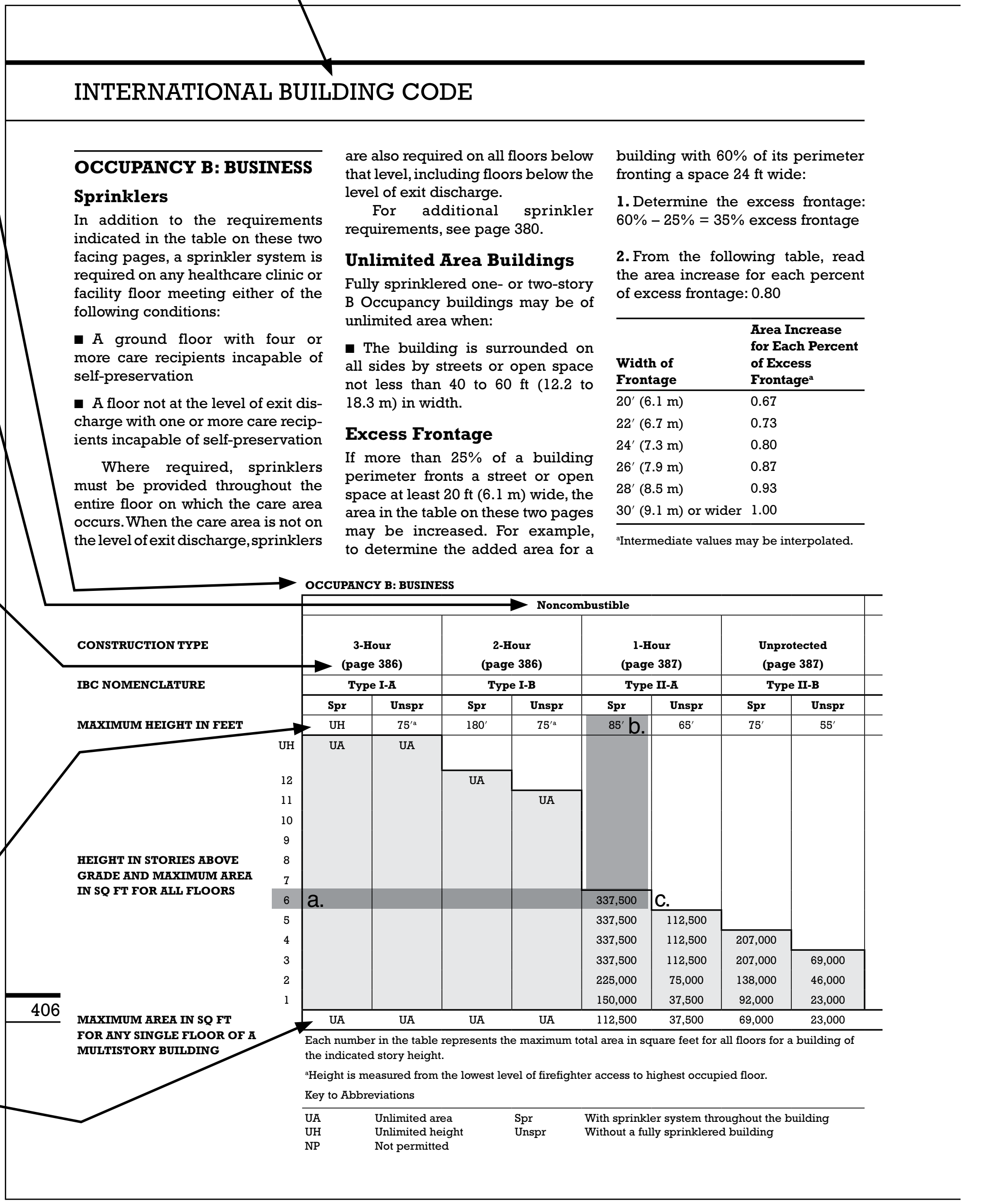
2. The Occupancy classification is given in the upper-left corner of the table. If you are not sure about the Occupancy or Occupancies into which your building falls, consult the indexes on pages 6–12.

3. Each pair of columns represents one Construction Type. For specific information on the different materials and modes of construction that conform to that Type, follow the page reference given here.

4. Noncombustible Construction Types appear toward the left in the table, Mixed Combustible/Noncombustible Construction Types appear in the middle of the table, and Combustible Construction Types appear toward the right.

5. For each Construction Type, the paired columns tabulate height and area information for buildings with different sprinkler conditions, such as fully sprinklered throughout (Spr), or unsprinklered or only partially sprinklered (Unspr).

6. The bottom row of the table lists the maximum area for any single floor within a multistory building.



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OCCUPANCY B: BUSINESS

Sprinklers

In addition to the requirements indicated in the table on these two facing pages, a sprinkler system is required on any healthcare clinic or facility floor meeting either of the following conditions:

- A ground floor with four or more care recipients incapable of self-preservation
- A floor not at the level of exit discharge with one or more care recipients incapable of self-preservation

Where required, sprinklers must be provided throughout the entire floor on which the care area occurs. When the care area is not on the level of exit discharge, sprinklers are also required on all floors below that level, including floors below the level of exit discharge.

For additional sprinkler requirements, see page 380.

Unlimited Area Buildings

Fully sprinklered one- or two-story B Occupancy buildings may be of unlimited area when:

- The building is surrounded on all sides by streets or open space not less than 40 to 60 ft (12.2 to 18.3 m) in width.

Excess Frontage

If more than 25% of a building perimeter fronts a street or open space at least 20 ft (6.1 m) wide, the area in the table on these two pages may be increased. For example, to determine the added area for a building with 60% of its perimeter fronting a space 24 ft wide:

1. Determine the excess frontage: 60% – 25% = 35% excess frontage

2. From the following table, read the area increase for each percent of excess frontage: 0.80

Width of Frontage	Area Increase for Each Percent of Excess Frontage[a]
20′ (6.1 m)	0.67
22′ (6.7 m)	0.73
24′ (7.3 m)	0.80
26′ (7.9 m)	0.87
28′ (8.5 m)	0.93
30′ (9.1 m) or wider	1.00

[a]Intermediate values may be interpolated.

OCCUPANCY B: BUSINESS

		Noncombustible							
CONSTRUCTION TYPE		**3-Hour (page 386)**		**2-Hour (page 386)**		**1-Hour (page 387)**		**Unprotected (page 387)**	
IBC NOMENCLATURE		**Type I-A**		**Type I-B**		**Type II-A**		**Type II-B**	
		Spr	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**
MAXIMUM HEIGHT IN FEET		UH	75′[a]	180′	75′[a]	85′ b.	65′	75′	55′
HEIGHT IN STORIES ABOVE GRADE AND MAXIMUM AREA IN SQ FT FOR ALL FLOORS	UH	UA	UA						
	12			UA					
	11				UA				
	10								
	9								
	8								
	7								
	6	a.				337,500	c.		
	5					337,500	112,500		
	4					337,500	112,500	207,000	
	3					337,500	112,500	207,000	69,000
	2					225,000	75,000	138,000	46,000
	1					150,000	37,500	92,000	23,000
MAXIMUM AREA IN SQ FT FOR ANY SINGLE FLOOR OF A MULTISTORY BUILDING		UA	UA	UA	UA	112,500	37,500	69,000	23,000

Each number in the table represents the maximum total area in square feet for all floors for a building of the indicated story height.

[a]Height is measured from the lowest level of firefighter access to highest occupied floor.

Key to Abbreviations

UA	Unlimited area	Spr	With sprinkler system throughout the building
UH	Unlimited height	Unspr	Without a fully sprinklered building
NP	Not permitted		

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3. Calculate the area increase: 0.80 × 35% = 28%

4. The added area for excess frontage is determined using unsprinklered area allowances. To find the added area for one floor, read the lowest figure in the unsprinklered column for your construction type and multiply this figure by the area increase calculated in the previous step. Continuing the example, assuming a Type II-B building, sprinklered or unsprinklered with the excess frontage described previously, the added area per floor would be 28% × 23,000 sq ft = 6440 sq ft. For a two-story building, the added area would be twice this amount, or 12,880 sq ft, and for a building three or more stories in height, 3 times this amount, or 19,320 sq ft.

Measurements

Height is measured from the average finished ground level adjoining the building to the average level of the highest roof. Floor area is measured within exterior walls or exterior walls and fire walls, exclusive of courtyards. Basements are not included in area calculations, provided that their area does not exceed the area permitted for a one-story building.

1 ft = 304.8 mm, 1 sq ft = 0.0929 m^2

Further Information

Occupancy classifications: page 6.
Mixed-use buildings: page 374.
Which code to consult: pages 5–6.

Mixed Combustible/Noncombustible												Combustible				
Ordinary				Mass Timber & Heavy Timber								Wood Light Frame				
1-Hour (page 387)		Unprotected (page 387)		Mass Timber (page 388)						Heavy Timber (page 388)		1-Hour (page 391)		Unprotected (page 391)		
Type III-A		Type III-B		Type IV-A		Type IV-B		Type IV-C		Type IV-HT		Type V-A		Type V-B		
Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	
85′	65′	75′	55′	270′	65′	180′	65′	85′	65′	85′	65′	70′	50′	60′	40′	
				18 stories max												UH
				972,000		648,000										12
				972,000		648,000										11
				972,000		648,000										10
				972,000		648,000		405,000								9
				972,000		648,000		405,000								8
				972,000		648,000		405,000								7
256,500				972,000		648,000		405,000		324,000						6
256,500	85,500			972,000	324,000	648,000	216,000	405,000	135,000	324,000	108,000					5
256,500	85,500	171,000		972,000	324,000	648,000	216,000	405,000	135,000	324,000	108,000	162,000				4
256,500	85,500	171,000	57,000	972,000	324,000	648,000	216,000	405,000	135,000	324,000	108,000	162,000	54,000	81,000		3
171,000	57,000	114,000	38,000	648,000	216,000	432,000	144,000	270,000	90,000	216,000	72,000	108,000	36,000	54,000	18,000	2
114,000	28,500	76,000	19,000	432,000	108,000	288,000	72,000	180,000	45,000	144,000	36,000	72,000	18,000	36,000	9,000	1
85,500	28,500	57,000	19,000	324,000	108,000	216,000	72,000	135,000	45,000	108,000	36,000	54,000	18,000	27,000	9,000	

This table was compiled from information contained in the International Building Code 2021. It does not represent an official interpretation by the organization that issues this code.

7. For the International Building Code, the tabulated areas represent the maximum total area for all floors of the building.

8. As an example of the use of this chart, under the International Building Code, a fully sprinklered B Occupancy building of 1-Hour Noncombustible Type II-A Construction, may be no more than (see shaded areas on chart):

- **a.** six stories or
- **b.** 85 ft tall, whichever is less,
- **c.** with a total floor area (on all floors) no larger than 337,500 sq ft.

9. As another example, if we wish to construct a four-story unsprinklered B Occupancy building with 27,500 sq ft per floor, or 110,000 sq ft total area, we must use at least Type II-A 1-Hour Noncombustible Construction or any Mass Timber Type IV-A, -B, or -C Construction. Or, with the addition of sprinklers, we could also use any other Construction Type except Unprotected Wood Light Frame Type V-B. By following the page references at the heads of these columns, we can determine exactly what each of these Construction Types is and proceed to preliminary configuration and sizing of the structural system we select.

The reference tables appearing on the following pages are for preliminary design purposes only. They represent the authors' interpretation of certain major provisions of the International Building Code. No official interpretation has been sought from or granted by the International Code Council. For final preparation of building plans, you must consult the building codes and regulations in effect in your project's locale.

OCCUPANCY A-1: ASSEMBLY, THEATERS

Sprinklers

In addition to the requirements indicated in the table on these two facing pages, a sprinkler system is required for A-1 Occupancy building *fire areas* meeting any of the following conditions:

- When not located on the level of exit discharge
- Exceeding 12,000 sq ft (1115 m^2) in area
- With an occupant load of 300 or more
- Containing multitheater complexes

Where required, sprinklers must be provided throughout the floors on which the fire area occurs. When the fire area is not on the level of exit discharge, sprinklers are also required on all floors between it and the exit level, and on the exit level itself. For additional sprinkler requirements, see page 380.

Unlimited Area Buildings

Fully sprinklered one-story motion picture theater buildings may be of unlimited area when all of the following conditions are met:

- The Construction Type is noncombustible.
- The building is surrounded on all sides by streets or open space not less than 40 to 60 ft (12.2 to 18.3 m) in width.

Fully sprinklered, one-story mixed-occupancy buildings including A-1 Occupancies may be of unlimited area when all of the following conditions are met:

- The construction is other than Type V Wood Light Frame.
- The A-1 Occupancies are separated from other Occupancies as required for Separated Occupancies (see page 374).
- The A-1 Occupancy areas do not themselves exceed the area limits in the chart on these two facing pages.
- The building is surrounded on all sides by streets or open space not less than 40 to 60 ft (12.2 to 18.3 m) in width and exits discharge directly to the building exterior.

OCCUPANCY A-1: ASSEMBLY, THEATERS

		Noncombustible							
CONSTRUCTION TYPE		**3-Hour (page 386)**		**2-Hour (page 386)**		**1-Hour (page 387)**		**Unprotected (page 387)**	
IBC NOMENCLATURE		**Type I-A**		**Type I-B**		**Type II-A**		**Type II-B**	
		Spr	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**
MAXIMUM HEIGHT IN FEET		UH	75′[a]	180′	75′[a]	85′	65′	75′	55′
HEIGHT IN STORIES ABOVE GRADE AND MAXIMUM AREA IN SQ FT FOR ALL FLOORS	UH	UA	UA						
	12								
	11								
	10								
	9								
	8								
	7								
	6			UA					
	5				UA				
	4					139,500			
	3					139,500	46,500	76,500	
	2					93,000	31,000	51,000	17,000
	1					62,000	15,500	34,000	8,500
MAXIMUM AREA IN SQ FT FOR ANY SINGLE FLOOR OF A MULTIFLOOR BUILDING		UA	UA	UA	UA	46,500	15,500	25,500	8,500

Each number in the table represents the maximum total area in square feet for all floors for a building of the indicated story height.

[a]Height is measured from the lowest level of firefighter access to highest occupied floor.

Key to Abbreviations

UA	Unlimited area	Spr	With sprinkler system throughout the building
UH	Unlimited height	Unspr	Without a fully sprinklered building
NP	Not permitted		

Excess Frontage

If more than 25% of a building perimeter fronts a street or open space at least 20 ft (6.1 m) wide, the area in the table on these two pages may be increased. For example, to determine the added area for a building with 60% of its perimeter fronting a space 24 ft wide:

1. Determine the excess frontage: 60% – 25% = 35% excess frontage

2. From the following table, read the area increase for each percent of excess frontage: 0.80

3. Calculate the area increase: 0.80 × 35% = 28%

4. In Assembly Occupancy buildings, the added area for excess frontage is determined using unsprinklered area allowances. To find the added area for one floor, read the lowest figure in the unsprinklered column for your construction type and multiply this figure by the area increase calculated in the previous step. Continuing the example, assuming an A-1 Occupancy, Type III-A building, sprinklered or unsprinklered with the excess frontage described previously, the added area per floor would be 28% × 14,000 sq ft = 3920 sq ft. For a two-story building, the added area would be twice this amount, or 7840 sq ft, and for a building three or more stories in height, 3 times this amount, or 11,760 sq ft.

Width of Frontage	Area Increase for Each Percent of Excess Frontage[a]
20′ (6.1 m)	0.67
22′ (6.7 m)	0.73
24′ (7.3 m)	0.80
26′ (7.9 m)	0.87
28′ (8.5 m)	0.93
30′ (9.1 m) or wider	1.00

[a]Intermediate values may be interpolated.

Measurements

Height is measured from the average finished ground level adjoining the building to the average level of the highest roof. Floor area is measured within exterior walls, exclusive of courtyards. Basements are not included in area calculations, provided that their area does not exceed the area permitted for a one-story building.

$$1\,\text{ft} = 304.8\,\text{mm}, 1\,\text{sq ft} = 0.0929\,\text{m}^2$$

Mixed Combustible/Noncombustible												Combustible				
Ordinary				Mass Timber & Heavy Timber								Wood Light Frame				
1-Hour (page 387)		Unprotected (page 387)		Mass Timber (page 388)						Heavy Timber (page 388)		1-Hour (page 391)		Unprotected (page 391)		
Type III-A		Type III-B		Type IV-A		Type IV-B		Type IV-C		Type IV-HT		Type V-A		Type V-B		
Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	
85’	65’	75’	55’	270’	65’	180’	65’	85’	65’	85’	65’	70’	50’	60’	40’	
																UH
																12
																11
																10
				405,000												9
				405,000												8
				405,000												7
				405,000		270,000										6
				405,000		270,000										5
126,000				405,000		270,000		168,750		135,000						4
126,000	42,000	76,500		405,000	135,000	270,000	90,000	168,750	56,250	135,000	45,000	103,500				3
84,000	28,000	51,000	17,000	270,000	90,000	180,000	60,000	112,500	37,500	90,000	30,000	69,000	23,000	33,000		2
56,000	14,000	34,000	8,500	180,000	45,000	120,000	30,000	75,000	18,750	60,000	15,000	46,000	11,500	22,000	5,500	1
42,000	14,000	25,500	8,500	135,000	45,000	90,000	30,000	56,250	18,750	45,000	15,000	34,500	11,500	16,500	5,500	

This table was compiled from information contained in the International Building Code 2021. It does not represent an official interpretation by the organization that issues this code.

OCCUPANCY A-2: ASSEMBLY, FOOD AND DRINK ESTABLISHMENTS

Sprinklers

In addition to the requirements indicated in the table on these two facing pages, a sprinkler system is required for A-2 Occupancy *fire areas* meeting any of the following conditions:

- When not located on the level of exit discharge
- Exceeding 5000 sq ft (465 m²) in area
- With an occupant load of 100 or more

Where required, sprinklers must be provided throughout the floors on which the fire area occurs. When the fire area is not on the level of exit discharge, sprinklers are also required on all floors between it and the exit level, and on the exit level itself.

For additional sprinkler requirements, see page 380.

Unlimited-Area Buildings

Fully sprinklered one-story mixed-occupancy buildings including A-2 Occupancies may be of unlimited area when all of the following conditions are met:

- The Construction Type is other than Wood Light Frame.
- The A-2 Occupancies are separated from other Occupancies as required for Separated Occupancies (see page 374).

OCCUPANCY A-2: ASSEMBLY, FOOD AND DRINK ESTABLISHMENTS

	Noncombustible							
CONSTRUCTION TYPE	**3-Hour (page 386)**		**2-Hour (page 386)**		**1-Hour (page 387)**		**Unprotected (page 387)**	
IBC NOMENCLATURE	**Type I-A**		**Type I-B**		**Type II-A**		**Type II-B**	
	Spr	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**
MAXIMUM HEIGHT IN FEET	UH	75′[a]	180′	75′[a]	85′	65′	75′	55′
HEIGHT IN STORIES ABOVE GRADE AND MAXIMUM AREA IN SQ FT FOR ALL FLOORS UH	UA	UA						
12			UA					
11				UA				
10								
9								
8								
7								
6								
5								
4					139,500			
3					139,500	46,500	85,500	
2					93,000	31,000	57,000	19,000
1					62,000	15,500	38,000	9,500
MAXIMUM AREA IN SQ FT FOR ANY SINGLE FLOOR OF A MULTIFLOOR BUILDING	UA	UA	UA	UA	46,500	15,500	28,500	9,500

Each number in the table represents the maximum total area in square feet for all floors for a building of the indicated story height.

[a]Height is measured from the lowest level of firefighter access to highest occupied floor.

Key to Abbreviations

UA	Unlimited area	Spr	With sprinkler system throughout the building
UH	Unlimited height	Unspr	Without a fully sprinklered building
NP	Not permitted		

- The A-2 Occupancy areas do not themselves exceed the area limits in the chart on these two facing pages.
- All exits from A-2 Occupancy areas discharge directly to the building's exterior.
- The building is surrounded on all sides by streets or open space not less than 40 to 60 ft (12.2 to 18.3 m) in width.

Excess Frontage

See page 397 for an explanation of applying excess frontage to allowable area increases in Assembly Occupancy buildings.

Measurements

Height is measured from the average finished ground level adjoining the building to the average level of the highest roof. Floor area is measured within exterior walls or exterior walls and fire walls, exclusive of courtyards. Basements are not included in area calculations, provided that their area does not exceed the area permitted for a one-story building.

$1\,ft = 304.8\,mm, 1\,sq\,ft = 0.0929\,m^2$

Further Information

Occupancy classifications: page 6.
Mixed-use buildings: page 374.
Which code to consult: pages 5–6.

	Mixed Combustible/Noncombustible												**Combustible**				
	Ordinary				**Mass Timber & Heavy Timber**								**Wood Light Frame**				
	1-Hour (page 387)		**Unprotected (page 387)**		**Mass Timber (page 388)**						**Heavy Timber (page 388)**		**1-Hour (page 391)**		**Unprotected (page 391)**		
	Type III-A		**Type III-B**		**Type IV-A**		**Type IV-B**		**Type IV-C**		**Type IV-HT**		**Type V-A**		**Type V-B**		
	Spr	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**	
	85′	65′	75′	55′	270′	65′	180′	65′	85′	65′	85′	65′	70′	50′	60′	40′	
					18 stories max												UH
					405,000		270,000										12
					405,000		270,000										11
					405,000		270,000										10
					405,000		270,000										9
					405,000		270,000										8
					405,000		270,000										7
					405,000		270,000		168,750								6
					405,000		270,000		168,750								5
	126,000				405,000		270,000		168,750		135,000						4
	126,000	42,000	85,500		405,000	135,000	270,000	90,000	168,750	56,250	135,000	45,000	103,500				3
	84,000	28,000	57,000	19,000	270,000	90,000	180,000	60,000	112,500	37,500	90,000	30,000	69,000	23,000	36,000		2
	56,000	14,000	38,000	9,500	180,000	45,000	120,000	30,000	75,000	18,750	60,000	15,000	46,000	11,500	24,000	6,000	1
	42,000	14,000	28,500	9,500	135,000	45,000	90,000	30,000	56,250	18,750	45,000	15,000	34,500	11,500	18,000	6,000	

This table was compiled from information contained in the International Building Code 2021. It does not represent an official interpretation by the organization that issues this code.

OCCUPANCY A-3: ASSEMBLY, MISCELLANEOUS

Sprinklers

In addition to the requirements indicated in the table on these two facing pages, a sprinkler system is required for A-3 Occupancy *fire areas* meeting any of the following conditions:

- When not located on the level of exit discharge
- Exceeding 12,000 sq ft (1115 m^2) in area
- With an occupant load of 300 or more

Where required, sprinklers must be provided throughout the floors on which the fire area occurs. When the fire area is not on the level of exit discharge, sprinklers are also required on all floors between it and the exit level, and on the exit level itself.

For additional sprinkler requirements, see page 380.

Unlimited Area Buildings

Fully sprinklered one-story A-3 Occupancy buildings used for religious worship, community halls, dance halls, exhibition spaces, gymnasiums, lecture halls, or indoor swimming pools or tennis courts may be of unlimited area when all of the following conditions are met:

- The Construction Type is noncombustible.
- There are no stages or platforms in the building.
- The building is surrounded on all sides by streets or open space not less than 40 to 60 ft (12.2 to 18.3 m) in width.

Alternatively, the building may be of any Construction Type other than Wood Light Frame if, in

OCCUPANCY A-3: ASSEMBLY, MISCELLANEOUS

		Noncombustible							
CONSTRUCTION TYPE		**3-Hour (page 386)**		**2-Hour (page 386)**		**1-Hour (page 387)**		**Unprotected (page 387)**	
IBC NOMENCLATURE		**Type I-A**		**Type I-B**		**Type II-A**		**Type II-B**	
		Spr	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**
MAXIMUM HEIGHT IN FEET		UH	75′[a]	180′	75′[a]	85′	65′	75′	55′
HEIGHT IN STORIES ABOVE GRADE AND MAXIMUM AREA IN SQ FT FOR ALL FLOORS	UH	UA	UA						
	12			UA					
	11				UA				
	10								
	9								
	8								
	7								
	6								
	5								
	4					139,500			
	3					139,500	46,500	85,500	
	2					93,000	31,000	57,000	19,000
	1					62,000	15,500	38,000	9,500
MAXIMUM AREA IN SQ FT FOR ANY SINGLE FLOOR OF A MULTISTORY BUILDING		UA	UA	UA	UA	46,500	15,500	28,500	9,500

Each number in the table represents the maximum total area in square feet for all floors for a building of the indicated story height.

[a]Height is measured from the lowest level of firefighter access to highest occupied floor.

Key to Abbreviations

UA	Unlimited area	Spr	With sprinkler system throughout the building
UH	Unlimited height	Unspr	Without a fully sprinklered building
NP	Not permitted		

addition to the above conditions, the assembly floor is within 21 in. (533 mm) of grade level and all exits are provided with ramps to reach grade.

Excess Frontage

See page 397 for an explanation of applying excess frontage to allowable area increases in Assembly Occupancy buildings.

Measurements

Height is measured from the average finished ground level adjoining the building to the average level of the highest roof. Floor area is measured within exterior walls or exterior walls and fire walls, exclusive of courtyards. Basements are not included in area calculations, provided that their area does not exceed the area permitted for a one-story building.

$$1\,\text{ft} = 304.8\,\text{mm}, 1\,\text{sq ft} = 0.0929\,\text{m}^2$$

Further Information

Occupancy classifications: page 6.
Mixed-use buildings: page 374.
Which code to consult: pages 5–6.

Mixed Combustible/Noncombustible												Combustible				
Ordinary				Mass Timber & Heavy Timber								Wood Light Frame				
1-Hour (page 387)		Unprotected (page 387)		Mass Timber (page 388)						Heavy Timber (page 388)		1-Hour (page 391)		Unprotected (page 391)		
Type III-A		Type III-B		Type IV-A		Type IV-B		Type IV-C		Type IV-HT		Type V-A		Type V-B		
Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	
85′	65′	75′	55′	270′	65′	180′	65′	85′	65′	85′	65′	70′	50′	60′	40′	
				18 stories max												UH
				405,000		270,000										12
				405,000		270,000										11
				405,000		270,000										10
				405,000		270,000										9
				405,000		270,000										8
				405,000		270,000										7
				405,000		270,000		168,750								6
				405,000		270,000		168,750								5
126,000				405,000		270,000		168,750		135,000						4
126,000	42,000	85,500		405,000	135,000	270,000	90,000	168,750	56,250	135,000	45,000	103,500				3
84,000	28,000	57,000	19,000	270,000	90,000	180,000	60,000	112,500	37,500	90,000	30,000	69,000	23,000	36,000		2
56,000	14,000	38,000	9,500	180,000	45,000	120,000	30,000	75,000	18,750	60,000	15,000	46,000	11,500	24,000	6,000	1
42,000	14,000	28,500	9,500	135,000	45,000	90,000	30,000	56,250	18,750	45,000	15,000	34,500	11,500	18,000	6,000	

This table was compiled from information contained in the International Building Code 2021. It does not represent an official interpretation by the organization that issues this code.

OCCUPANCY A-4: ASSEMBLY, INDOOR ARENAS

Sprinklers

In addition to the requirements indicated in the table on these two facing pages, a sprinkler system is required for A-4 Occupancy *fire areas* meeting any of the following conditions:

- When not located on the level of exit discharge
- Exceeding 12,000 sq ft (1115 m^2) in area
- With an occupant load of 300 or more

Where required, sprinklers must be provided throughout the floors on which the fire area occurs. When the fire area is not on the level of exit discharge, sprinklers are also required on all floors between it and the exit level, and on the exit level itself.

For additional sprinkler requirements, see page 380.

Unlimited Area Buildings

Fully sprinklered, one-story A-4 Occupancy buildings may be of unlimited area when all of the following conditions are met:

- The construction is other than Type V Wood Light Frame.
- The building is surrounded on all sides by streets or open space not less than 40 to 60 ft (12.2 to 18.3 m) in width.

Sprinklers need not cover areas occupied by indoor sport activities, provided that the exit doors for those areas lead directly to the outside.

Excess Frontage

See page 397 for an explanation of applying excess frontage to allowable area increases in Assembly Occupancy buildings.

OCCUPANCY A-4: ASSEMBLY, INDOOR ARENAS

		Noncombustible							
CONSTRUCTION TYPE		**3-Hour (page 386)**		**2-Hour (page 386)**		**1-Hour (page 387)**		**Unprotected (page 387)**	
IBC NOMENCLATURE		**Type I-A**		**Type I-B**		**Type II-A**		**Type II-B**	
		Spr	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**
MAXIMUM HEIGHT IN FEET		UH	75′[a]	180′	75′[a]	85′	65′	75′	55′
HEIGHT IN STORIES ABOVE GRADE AND MAXIMUM AREA IN SQ FT FOR ALL FLOORS	UH	UA	UA						
	12			UA					
	11				UA				
	10								
	9								
	8								
	7								
	6								
	5								
	4					139,500			
	3					139,500	46,500	85,500	
	2					93,000	31,000	57,000	19,000
	1					62,000	15,500	38,000	9,500
MAXIMUM AREA IN SQ FT FOR ANY SINGLE FLOOR OF A MULTISTORY BUILDING		UA	UA	UA	UA	46,500	15,500	28,500	9,500

Each number in the table represents the maximum total area in square feet for all floors for a building of the indicated story height.

[a]Height is measured from the lowest level of firefighter access to highest occupied floor.

Key to Abbreviations

UA	Unlimited area	Spr	With sprinkler system throughout the building
UH	Unlimited height	Unspr	Without a fully sprinklered building
NP	Not permitted		

INTERNATIONAL BUILDING CODE

Measurements

Height is measured from the average finished ground level adjoining the building to the average level of the highest roof. Floor area is measured within exterior walls or exterior walls and fire walls, exclusive of courtyards. Basements are not included in area calculations, provided that their area does not exceed the area permitted for a one-story building.

1 ft = 304.8 mm, 1 sq ft = 0.0929 m^2

Further Information

Occupancy classifications: page 6.
Mixed-use buildings: page 374.
Which code to consult: pages 5–6.

Mixed Combustible/Noncombustible												Combustible				
Ordinary				Mass Timber & Heavy Timber								Wood Light Frame				
1-Hour (page 387)		Unprotected (page 387)		Mass Timber (page 388)						Heavy Timber (page 388)		1-Hour (page 391)		Unprotected (page 391)		
Type III-A		Type III-B		Type IV-A		Type IV-B		Type IV-C		Type IV-HT		Type V-A		Type V-B		
Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	
85′	65′	75′	55′	270′	65′	180′	65′	85′	65′	85′	65′	70′	50′	60′	40′	
				18 stories max												UH
				405,000		270,000										12
				405,000		270,000										11
				405,000		270,000										10
				405,000		270,000										9
				405,000		270,000										8
				405,000		270,000										7
				405,000		270,000		168,750								6
				405,000		270,000		168,750								5
126,000				405,000		270,000		168,750		135,000						4
126,000	42,000	85,500		405,000	135,000	270,000	90,000	168,750	56,250	135,000	45,000	103,500				3
84,000	28,000	57,000	19,000	270,000	90,000	180,000	60,000	112,500	37,500	90,000	30,000	69,000	23,000	36,000		2
56,000	14,000	38,000	9,500	180,000	45,000	120,000	30,000	75,000	18,750	60,000	15,000	46,000	11,500	24,000	6,000	1
42,000	14,000	28,500	9,500	135,000	45,000	90,000	30,000	56,250	18,750	45,000	15,000	34,500	11,500	18,000	6,000	

This table was compiled from information contained in the International Building Code 2021. It does not represent an official interpretation by the organization that issues this code.

OCCUPANCY A-5: ASSEMBLY, OUTDOOR ARENAS

Sprinklers

For buildings of this type, sprinklers are required for:

- Enclosed accessory use areas greater than 1000 sq ft (93 m²) in floor area

For additional sprinkler requirements, see page 380.

Measurements

Height is measured from the average finished ground level adjoining the building to the average level of the highest roof. Floor area is measured within exterior walls or exterior walls and fire walls, exclusive of courtyards.

$1\,\text{ft} = 304.8\,\text{mm}, 1\,\text{sq ft} = 0.0929\,\text{m}^2$

Further Information

Occupancy classifications: page 6.
Mixed-use buildings: page 374.
Which code to consult: pages 5–6.

OCCUPANCY A-5: ASSEMBLY, OUTDOOR ARENAS

		Noncombustible							
CONSTRUCTION TYPE		3-Hour (page 386)		2-Hour (page 386)		1-Hour (page 387)		Unprotected (page 387)	
IBC NOMENCLATURE		Type I-A		Type I-B		Type II-A		Type II-B	
		Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr
MAXIMUM HEIGHT IN FEET		UH	75′[a]	180′	75′[a]	85′	65′	75′	55′
HEIGHT IN STORIES ABOVE GRADE AND MAXIMUM AREA IN SQ FT FOR ALL FLOORS	UH	UA	UA	UA	UA	UA	UA	UA	UA
	12								
	11								
	10								
	9								
	8								
	7								
	6								
	5								
	4								
	3								
	2								
	1								
MAXIMUM AREA IN SQ FT FOR ANY SINGLE FLOOR OF A MULTISTORY BUILDING		UA	UA	UA	UA	UA	UA	UA	UA

Each number in the table represents the maximum total area in square feet for all floors for a building of the indicated story height.

[a]Height is measured from the lowest level of firefighter access to highest occupied floor.

Key to Abbreviations

UA	Unlimited area	Spr	With sprinkler system throughout the building
UH	Unlimited height	Unspr	Without a fully sprinklered building
NP	Not permitted		

Mixed Combustible/Noncombustible												Combustible				
Ordinary				Mass Timber & Heavy Timber								Wood Light Frame				
1-Hour (page 387)		Unprotected (page 387)		Mass Timber (page 388)						Heavy Timber (page 388)		1-Hour (page 391)		Unprotected (page 391)		
Type III-A		Type III-B		Type IV-A		Type IV-B		Type IV-C		Type IV-HT		Type V-A		Type V-B		
Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	
85′	65′	75′	55′	270′	65′	180′	65′	85′	65′	85′	65′	70′	50′	60′	40′	
UA	UA	UA	UA	UA		UA		UA		UA	UA	UA	UA	UA	UA	UH
																12
																11
																10
																9
																8
																7
																6
																5
																4
																3
																2
					UA		UA		UA							1
UA	UA	UA	UA	UA	UA	UA	UA	UA	UA	UA	UA	UA	UA	UA	UA	

This table was compiled from information contained in the International Building Code 2021. It does not represent an official interpretation by the organization that issues this code.

OCCUPANCY B: BUSINESS

Sprinklers

In addition to the requirements indicated in the table on these two facing pages, a sprinkler system is required on any healthcare clinic or facility floor meeting either of the following conditions:

- A ground floor with four or more care recipients incapable of self-preservation
- A floor not at the level of exit discharge with one or more care recipients incapable of self-preservation

Where required, sprinklers must be provided throughout the entire floor on which the care area occurs. When the care area is not on the level of exit discharge, sprinklers are also required on all floors below that level, including floors below the level of exit discharge.

For additional sprinkler requirements, see page 380.

Unlimited Area Buildings

Fully sprinklered one- or two-story B Occupancy buildings may be of unlimited area when:

- The building is surrounded on all sides by streets or open space not less than 40 to 60 ft (12.2 to 18.3 m) in width.

Excess Frontage

If more than 25% of a building perimeter fronts a street or open space at least 20 ft (6.1 m) wide, the area in the table on these two pages may be increased. For example, to determine the added area for a building with 60% of its perimeter fronting a space 24 ft wide:

1. Determine the excess frontage: 60% – 25% = 35% excess frontage

2. From the following table, read the area increase for each percent of excess frontage: 0.80

Width of Frontage	Area Increase for Each Percent of Excess Frontage[a]
20′ (6.1 m)	0.67
22′ (6.7 m)	0.73
24′ (7.3 m)	0.80
26′ (7.9 m)	0.87
28′ (8.5 m)	0.93
30′ (9.1 m) or wider	1.00

[a]Intermediate values may be interpolated.

OCCUPANCY B: BUSINESS

		Noncombustible							
CONSTRUCTION TYPE		**3-Hour (page 386)**		**2-Hour (page 386)**		**1-Hour (page 387)**		**Unprotected (page 387)**	
IBC NOMENCLATURE		**Type I-A**		**Type I-B**		**Type II-A**		**Type II-B**	
		Spr	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**
MAXIMUM HEIGHT IN FEET		UH	75′[a]	180′	75′[a]	85′	65′	75′	55′
HEIGHT IN STORIES ABOVE GRADE AND MAXIMUM AREA IN SQ FT FOR ALL FLOORS	UH	UA	UA						
	12			UA					
	11				UA				
	10								
	9								
	8								
	7								
	6					337,500			
	5					337,500	112,500		
	4					337,500	112,500	207,000	
	3					337,500	112,500	207,000	69,000
	2					225,000	75,000	138,000	46,000
	1					150,000	37,500	92,000	23,000
MAXIMUM AREA IN SQ FT FOR ANY SINGLE FLOOR OF A MULTISTORY BUILDING		UA	UA	UA	UA	112,500	37,500	69,000	23,000

Each number in the table represents the maximum total area in square feet for all floors for a building of the indicated story height.

[a]Height is measured from the lowest level of firefighter access to highest occupied floor.

Key to Abbreviations

UA	Unlimited area	Spr	With sprinkler system throughout the building
UH	Unlimited height	Unspr	Without a fully sprinklered building
NP	Not permitted		

3. Calculate the area increase: 0.80 × 35% = 28%

4. The added area for excess frontage is determined using unsprinklered area allowances. To find the added area for one floor, read the lowest figure in the unsprinklered column for your construction type and multiply this figure by the area increase calculated in the previous step. Continuing the example, assuming a Type II-B building, sprinklered or unsprinklered with the excess frontage described previously, the added area per floor would be 28% × 23,000 sq ft = 6440 sq ft. For a two-story building, the added area would be twice this amount, or 12,880 sq ft, and for a building three or more stories in height, 3 times this amount, or 19,320 sq ft.

Measurements

Height is measured from the average finished ground level adjoining the building to the average level of the highest roof. Floor area is measured within exterior walls or exterior walls and fire walls, exclusive of courtyards. Basements are not included in area calculations, provided that their area does not exceed the area permitted for a one-story building.

$$1\,ft = 304.8\,mm, 1\,sq\,ft = 0.0929\,m^2$$

Further Information

Occupancy classifications: page 6.
Mixed-use buildings: page 374.
Which code to consult: pages 5–6.

Mixed Combustible/Noncombustible												Combustible				
Ordinary				Mass Timber & Heavy Timber								Wood Light Frame				
1-Hour (page 387)		Unprotected (page 387)		Mass Timber (page 388)						Heavy Timber (page 388)		1-Hour (page 391)		Unprotected (page 391)		
Type III-A		Type III-B		Type IV-A		Type IV-B		Type IV-C		Type IV-HT		Type V-A		Type V-B		
Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	
85′	65′	75′	55′	270′	65′	180′	65′	85′	65′	85′	65′	70′	50′	60′	40′	
				18 stories max												UH
				972,000		648,000										12
				972,000		648,000										11
				972,000		648,000										10
				972,000		648,000		405,000								9
				972,000		648,000		405,000								8
				972,000		648,000		405,000								7
256,500				972,000		648,000		405,000		324,000						6
256,500	85,500			972,000	324,000	648,000	216,000	405,000	135,000	324,000	108,000					5
256,500	85,500	171,000		972,000	324,000	648,000	216,000	405,000	135,000	324,000	108,000	162,000				4
256,500	85,500	171,000	57,000	972,000	324,000	648,000	216,000	405,000	135,000	324,000	108,000	162,000	54,000	81,000		3
171,000	57,000	114,000	38,000	648,000	216,000	432,000	144,000	270,000	90,000	216,000	72,000	108,000	36,000	54,000	18,000	2
114,000	28,500	76,000	19,000	432,000	108,000	288,000	72,000	180,000	45,000	144,000	36,000	72,000	18,000	36,000	9,000	1
85,500	28,500	57,000	19,000	324,000	108,000	216,000	72,000	135,000	45,000	108,000	36,000	54,000	18,000	27,000	9,000	

This table was compiled from information contained in the International Building Code 2021. It does not represent an official interpretation by the organization that issues this code.

OCCUPANCY E: EDUCATIONAL

Sprinklers

In addition to the requirements indicated in the table on these two facing pages, a sprinkler system is required for all E Occupancy *fire areas* meeting any of the following conditions:

- Exceeding 12,000 sq ft (1115 m^2) in area
- With an occupant load greater than 300
- The fire area is located on a floor other than the level of exit discharge

For additional sprinkler requirements, see page 380.

Unlimited Area Buildings

Fully sprinklered one-story E Occupancy buildings may be of unlimited area when all of the following conditions are met:

- The Construction Type is Noncombustible, 1-Hour Ordinary, or Mill.
- Each classroom has two independent means of egress, at least one of which leads directly to the exterior.
- The building is surrounded on all sides by streets or open space not less than 60 ft (12.2 to 18.3 m) in width.

Excess Frontage

If more than 25% of a building perimeter fronts a street or open space at least 20 ft (6.1 m) wide, the area in the table on these two pages may be increased. For example, to determine the added area for a building with 60% of its perimeter fronting a space 24 ft wide:

1. Determine the excess frontage: 60% – 25% = 35% excess frontage

2. From the following table, read the area increase for each percent of excess frontage: 0.80

Width of Frontage	Area Increase for Each Percent of Excess Frontage[a]
20′ (6.1 m)	0.67
22′ (6.7 m)	0.73
24′ (7.3 m)	0.80
26′ (7.9 m)	0.87
28′ (8.5 m)	0.93
30′ (9.1 m) or wider	1.00

[a]Intermediate values may be interpolated.

OCCUPANCY E: EDUCATIONAL

	Noncombustible							
CONSTRUCTION TYPE	3-Hour (page 386)		2-Hour (page 386)		1-Hour (page 387)		Unprotected (page 387)	
IBC NOMENCLATURE	Type I-A		Type I-B		Type II-A		Type II-B	
	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr
MAXIMUM HEIGHT IN FEET	UH	75′[a]	180′	75′[a]	85′	65′	75′	55′
HEIGHT IN STORIES ABOVE GRADE AND MAXIMUM AREA IN SQ FT FOR ALL FLOORS UH	UA	UA						
12								
11								
10								
9								
8								
7								
6			UA					
5				UA				
4					238,500			
3					238,500	79,500	130,500	
2					159,000	53,000	87,000	29,000
1					106,000	26,500	58,000	14,500
MAXIMUM AREA IN SQ FT FOR ANY SINGLE FLOOR OF A MULTISTORY BUILDING	UA	UA	UA	UA	79,500	26,500	43,500	14,500

Each number in the table represents the maximum total area in square feet for all floors for a building of the indicated story height.

[a]Height is measured from the lowest level of firefighter access to highest occupied floor.

Key to Abbreviations

UA	Unlimited area	Spr	With sprinkler system throughout the building
UH	Unlimited height	Unspr	Without a fully sprinklered building
NP	Not permitted		

3. Calculate the area increase: 0.80 × 35% = 28%

4. The added area for excess frontage is determined using unsprinklered area allowances. To find the added area for one floor, read the lowest figure in the unsprinklered column for your construction type and multiply this figure by the area increase calculated in the previous step. Continuing the example, assuming a Type III-A building, sprinklered or unsprinklered with the excess frontage described previously, the added area per floor would be 28% × 23,500 sq ft = 6580 sq ft. For a two-story building, the added area would be twice this amount, or 13,160 sq ft, and for a building three or more stories in height, 3 times this amount, or 19,740 sq ft.

Measurements

Height is measured from the average finished ground level adjoining the building to the average level of the highest roof. Floor area is measured within exterior walls or exterior walls and fire walls, exclusive of courtyards. Basements are not included in area calculations, provided that their area does not exceed the area permitted for a one-story building.

1 ft = 304.8 mm, 1 sq ft = 0.0929 m^2

Further Information

Occupancy classifications: page 6.
Mixed-use buildings: page 374.
Which code to consult: pages 5–6.

Mixed Combustible/Noncombustible												Combustible				
Ordinary				Mass Timber & Heavy Timber								Wood Light Frame				
1-Hour (page 387)		Unprotected (page 387)		Mass Timber (page 388)						Heavy Timber (page 388)		1-Hour (page 391)		Unprotected (page 391)		
Type III-A		Type III-B		Type IV-A		Type IV-B		Type IV-C		Type IV-HT		Type V-A		Type V-B		
Spr	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**	
85′	65′	75′	55′	270′	65′	180′	65′	85′	65′	85′	65′	70′	50′	60′	40′	
																UH
																12
																11
																10
				688,500												9
				688,500												8
				688,500												7
				688,500		459,000										6
				688,500		459,000										5
211,500				688,500		459,000		286,875		229,500						4
211,500	70,500	130,500		688,500	229,500	459,000	153,000	286,875		229,500	76,500					3
141,000	47,000	87,000	29,000	459,000	153,000	306,000	102,000	191,250	63,750	153,000	51,000	111,000		57,000		2
94,000	23,500	58,000	14,500	306,000	76,500	204,000	51,000	127,500	31,875	102,000	25,500	74,000	18,500	38,000	9,500	1
70,500	23,500	43,500	14,500	229,500	76,500	153,000	51,000	95,625	31,875	76,500	25,500	55,500	18,500	28,500	9,500	

This table was compiled from information contained in the International Building Code 2021. It does not represent an official interpretation by the organization that issues this code.

OCCUPANCY F-1: FACTORY, MODERATE-HAZARD

Sprinklers

A sprinkler system is required throughout *entire buildings* meeting any of the following conditions:

- Containing an F-1 Occupancy fire area exceeding 12,000 sq ft (1115 m^2)
- Containing an F-1 fire area located four or more stories above grade
- Containing multiple F-1 fire areas, including mezzanines, that in total exceed 24,000 sq ft (2230 m^2) in area

Because these conditions require the entire building to be sprinklered, all but relatively small buildings with F-1 Occupancies must be fully sprinklered. Where the table on these two facing pages indicates larger allowable areas for unsprinklered buildings, these figures may not apply to the whole building but may be used for other allowable area calculations such as mixed-occupancy conditions (pp. 374) or excess frontage.

A sprinkler system is required for all F-1 Occupancy *fire areas* meeting the following conditions:

- Fire areas exceeding exceed 2500 sq ft (232 m^2) used for the manufacture of upholstered furniture or mattresses, or containing woodworking operations with finely divided combustible waste
- Used for the manufacturer of distilled spirits

For additional sprinkler requirements, see page 380.

Unlimited Area Buildings

Fully sprinklered one- or two-story F-1 Occupancy buildings may be of unlimited area when:

- The building is surrounded on all sides by streets or open space not less than 40 to 60 ft (12.2 to 18.3 m) in width.

Excess Frontage

If more than 25% of a building perimeter fronts a street or open

OCCUPANCY F-1: FACTORY, MODERATE-HAZARD

		Noncombustible							
CONSTRUCTION TYPE		**3-Hour (page 386)**		**2-Hour (page 386)**		**1-Hour (page 387)**		**Unprotected (page 387)**	
IBC NOMENCLATURE		**Type I-A**		**Type I-B**		**Type II-A**		**Type II-B**	
		Spr	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**
MAXIMUM HEIGHT IN FEET		UH	75′[a]	180′	75′[a]	85′	65′	75′	55′
HEIGHT IN STORIES ABOVE GRADE AND MAXIMUM AREA IN SQ FT FOR ALL FLOORS	UH	UA							
	12			UA					
	11								
	10								
	9								
	8								
	7								
	6								
	5					225,000			
	4					225,000			
	3		UA		UA	225,000	75,000	139,500	
	2					150,000	50,000	93,000	31,000
	1					100,000	25,000	62,000	15,500
MAXIMUM AREA IN SQ FT FOR ANY SINGLE FLOOR OF A MULTISTORY BUILDING		UA	UA	UA	UA	75,000	25,000	46,500	15,500

Each number in the table represents the maximum total area in square feet for all floors for a building of the indicated story height.

[a]Height is measured from the lowest level of firefighter access to highest occupied floor.

Key to Abbreviations

UA	Unlimited area	Spr	With sprinkler system throughout the building
UH	Unlimited height	Unspr	Without a fully sprinklered building
NP	Not permitted		

space at least 20 ft (6.1 m) wide, the area in the table on these two pages may be increased. For example, to determine the added area for a building with 60% of its perimeter fronting a space 24 ft wide:

1. Determine the excess frontage: 60% – 25% = 35% excess frontage

2. From the following table, read the area increase for each percent of excess frontage: 0.80

3. Calculate the area increase: 0.80 × 35% = 28%

4. In Factory Occupancy buildings, the added area for excess frontage is determined using unsprinklered area allowances. To find the added area for one floor, read the lowest figure in the unsprinklered column

Width of Frontage	Area Increase for Each Percent of Excess Frontage[a]
20′ (6.1 m)	0.67
22′ (6.7 m)	0.73
24′ (7.3 m)	0.80
26′ (7.9 m)	0.87
28′ (8.5 m)	0.93
30′ (9.1 m) or wider	1.00

[a]Intermediate values may be interpolated.

for your construction type and multiply this figure by the area increase calculated in the previous step. Continuing the example, assuming an F-1 Occupancy Type II-B building, sprinklered or unsprinklered with the excess frontage described previously, the added area per floor would be 28% × 12,000 sq ft = 3360 sq ft. For a two-story building, the added area would be twice this amount, or 6720 sq ft, and for a building three or more stories in height, 3 times this amount, or 10,080 sq ft.

Measurements

Height is measured from the average finished ground level adjoining the building to the average level of the highest roof. Floor area is measured within exterior walls or exterior walls and fire walls, exclusive of courtyards. Basements are not included in area calculations, provided that their area does not exceed the area permitted for a one-story building.

$$1\,\text{ft} = 304.8\,\text{mm}, 1\,\text{sq ft} = 0.0929\,\text{m}^2$$

Mixed Combustible/Noncombustible												Combustible				
Ordinary				Mass Timber & Heavy Timber								Wood Light Frame				
1-Hour (page 387)		Unprotected (page 387)		Mass Timber (page 388)						Heavy Timber (page 388)		1-Hour (page 391)		Unprotected (page 391)		
Type III-A		Type III-B		Type IV-A		Type IV-B		Type IV-C		Type IV-HT		Type V-A		Type V-B		
Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	
85′	65′	75′	55′	270′	65′	180′	65′	85′	65′	85′	65′	70′	50′	60′	40′	
																UH
																12
																11
				904,500												10
				904,500												9
				904,500												8
				904,500		630,000										7
				904,500		630,000										6
				904,500		630,000		376,875		301,500						5
171,000				904,500		630,000		376,875		301,500						4
171,000	57,000	108,000		904,500	301,500	630,000	201,000	376,875	125,625	301,500	100,500	126,000				3
114,000	38,000	72,000	24,000	603,000	201,000	420,000	134,000	251,250	83,750	201,000	67,000	84,000	28,000	51,000		2
76,000	19,000	48,000	12,000	402,000	100,500	268,000	67,000	167,500	41,875	134,000	33,500	56,000	14,000	34,000	8,500	1
57,000	19,000	36,000	12,000	301,500	100,500	210,000	67,000	125,625	41,875	100,500	33,500	42,000	14,000	25,500	8,500	

This table was compiled from information contained in the International Building Code 2021. It does not represent an official interpretation by the organization that issues this code.

OCCUPANCY F-2: FACTORY, LOW-HAZARD

Sprinklers

Height and area sprinkler requirements for F-2 Occupancies are incorporated into the table on these two facing pages. For additional sprinkler requirements, see page 380.

Unlimited Height and Area Buildings

F-2 Occupancy buildings, either one-story unsprinklered or two-story fully sprinklered, may be of unlimited area when the building is surrounded on all sides by streets or open space not less than 40 to 60 ft (12.2 to 18.3 m) in width.

Certain fully sprinklered, non-public rack storage facilities may be of unlimited height and area.

Excess Frontage

See page 410 for an explanation of applying excess frontage to allowable area increases in Factory Occupancy buildings.

Measurements

Height is measured from the average finished ground level adjoining the building to the average level of the highest roof. Floor area is measured within exterior walls or exterior walls and fire walls, exclusive of courtyards. Basements are not included in area calculations, provided that their area does not exceed the area permitted for a one-story building.

1 ft = 304.8 mm, 1 sq ft = $0.0929\,m^2$

OCCUPANCY F-2: FACTORY, LOW-HAZARD

		Noncombustible							
CONSTRUCTION TYPE		**3-Hour (page 386)**		**2-Hour (page 386)**		**1-Hour (page 387)**		**Unprotected (page 387)**	
IBC NOMENCLATURE		**Type I-A**		**Type I-B**		**Type II-A**		**Type II-B**	
		Spr	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**
MAXIMUM HEIGHT IN FEET		UH	75′[a]	180′	75′[a]	85′	65′	75′	55′
HEIGHT IN STORIES ABOVE GRADE AND MAXIMUM AREA IN SQ FT FOR ALL FLOORS	UH	UA	UA						
	12			UA					
	11				UA				
	10								
	9								
	8								
	7								
	6					337,500			
	5					337,500	112,500		
	4					337,500	112,500	207,000	
	3					337,500	112,500	207,000	69,000
	2					225,000	75,000	138,000	46,000
	1					150,000	37,500	92,000	23,000
MAXIMUM AREA IN SQ FT FOR ANY SINGLE FLOOR OF A MULTISTORY BUILDING		UA	UA	UA	UA	112,500	37,500	69,000	23,000

Each number in the table represents the maximum total area in square feet for all floors for a building of the indicated story height.

[a]Height is measured from the lowest level of firefighter access to highest occupied floor.

Key to Abbreviations

UA	Unlimited area	Spr	With sprinkler system throughout the building
UH	Unlimited height	Unspr	Without a fully sprinklered building
NP	Not permitted		

INTERNATIONAL BUILDING CODE

Further Information

Occupancy classifications: page 6.
Mixed-use buildings: page 374.
Which code to consult: pages 5–6.

Mixed Combustible/Noncombustible												Combustible				
Ordinary				Mass Timber & Heavy Timber								Wood Light Frame				
1-Hour (page 387)		Unprotected (page 387)		Mass Timber (page 388)						Heavy Timber (page 388)		1-Hour (page 391)		Unprotected (page 391)		
Type III-A		Type III-B		Type IV-A		Type IV-B		Type IV-C		Type IV-HT		Type V-A		Type V-B		
Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	
85′	65′	75′	55′	270′	65′	180′	65′	85′	65′	85′	65′	70′	50′	60′	40′	
																UH
				1,363,500												12
				1,363,500												11
				1,363,500												10
				1,363,500												9
				1,363,500		909,000										8
				1,363,500		909,000										7
				1,363,500		909,000		568,125		454,500						6
256,500				1,363,500	454,500	909,000	303,000	568,125	189,375	454,500	151,500					5
256,500	85,500	162,000		1,363,500	454,500	909,000	303,000	568,125	189,375	454,500	151,500	189,000				4
256,500	85,500	162,000	54,000	1,363,500	454,500	909,000	303,000	568,125	189,375	454,500	151,500	189,000	63,000	117,000		3
171,000	57,000	108,000	36,000	909,000	303,000	606,000	202,000	378,750	126,250	303,000	101,000	126,000	42,000	78,000	26,000	2
114,000	28,500	72,000	18,000	606,000	151,500	404,000	101,000	252,500	63,125	202,000	50,500	84,000	21,000	52,000	13,000	1
85,500	28,500	54,000	18,000	454,500	151,500	303,000	101,000	189,375	63,125	151,500	50,500	63,000	21,000	39,000	13,000	

This table was compiled from information contained in the International Building Code 2021. It does not represent an official interpretation by the organization that issues this code.

OCCUPANCY H-1: HIGH-HAZARD, DETONATION

Special Requirements

All H-1 Occupancy buildings must be used solely for the H-1 use and be sprinklered throughout. They may not exceed one story in height or include basements, crawlspaces, or underfloor areas. They must be set back at least 75 ft (23 m) from adjacent properties and other buildings.

Due to the special hazards involved, Hazardous Occupancy buildings have many unique fire- and life-safety requirements. Be sure to consult applicable codes at the earliest stages of design.

Excess Frontage

The allowable area for an H-1 Occupancy building complying with the requirement for a 75-ft (23-m) setback from property lines and other buildings on all four sides may be increased by 75% from the amounts shown in the table on these two facing pages. For example, in such a case, a Type II-A building with H-1 Occupancy may have a floor area of 1.75 × 11,000 sq ft = 19,250 sq ft.

Measurements

Height is measured from the average finished ground level adjoining the building to the average level of the highest roof. Floor area is measured within exterior walls or exterior walls and fire walls, exclusive of courtyards.

1 ft = 304.8 mm, 1 sq ft = 0.0929 m^2

Further Information

Occupancy classifications: page 6.
Mixed-use buildings: page 374.
Which code to consult: pages 5–6.

OCCUPANCY H-1: HIGH-HAZARD, DETONATION

	Noncombustible							
CONSTRUCTION TYPE	**3-Hour (page 386)**		**2-Hour (page 386)**		**1-Hour (page 387)**		**Unprotected (page 387)**	
IBC NOMENCLATURE	**Type I-A**		**Type I-B**		**Type II-A**		**Type II-B**	
	Spr	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**
MAXIMUM HEIGHT IN FEET	UH		160′		65′		55′	
HEIGHT IN STORIES ABOVE GRADE AND MAXIMUM AREA IN SQ FT FOR ALL FLOORS UH								
12								
11								
10								
9								
8								
7								
6								
5								
4								
3								
2								
1	21,000	NP	16,500	NP	11,000	NP	7,000	NP

Each number in the table represents the maximum total area in square feet for all floors for a building of the indicated story height.

Key to Abbreviations

UA	Unlimited area	Spr	With sprinkler system throughout the building
UH	Unlimited height	Unspr	Without a fully sprinklered building
NP	Not permitted		

Mixed Combustible/Noncombustible												Combustible				
Ordinary				Mass Timber & Heavy Timber								Wood Light Frame				
1-Hour (page 387)		Unprotected (page 387)		Mass Timber (page 388)						Heavy Timber (page 388)		1-Hour (page 391)		Unprotected (page 391)		
Type III-A		Type III-B		Type IV-A		Type IV-B		Type IV-C		Type IV-HT		Type V-A		Type V-B		
Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	
65′		55′		120′		90′		65′		65′		50′				
																UH
																12
																11
																10
																9
																8
																7
																6
																5
																4
																3
																2
9,500	NP	7,000	NP	10,500	NP	10,500	NP	10,500	NP	10,500	NP	7,500	NP	NP	NP	1

This table was compiled from information contained in the International Building Code 2021. It does not represent an official interpretation by the organization that issues this code.

OCCUPANCY H-2: HIGH-HAZARD, ACCELERATED BURNING

Special Requirements

All H-2 *fire areas* must be sprinklered. For additional sprinkler requirements, see page 380.

If an H-2 Occupancy is greater than 1000 sq ft (93 m²) in area, it must be set back at least 30 ft (9.1 m) from adjacent properties and other buildings. In mixed-occupancy buildings, H-2 Occupancies must be Separated with 2- to 4-hour fire-resistance rated assemblies from the other Occupancies involved. Accessory and Nonseparated occupancy treatments are not permitted (see pages 374–375). In mixed-occupancy buildings, at least 25% of the perimeter of the H-2 Occupancy must be an exterior wall.

With greater quantities of hazardous material stored, greater separation distances from other buildings and public ways are required. Some H-2 Occupancy buildings are restricted solely to the H-2 use, limited to one story in height, and not permitted to include basements, crawlspaces, or other underfloor areas. Certain H-2 Occupancies of limited area and configuration are permitted to be included (as Separated Occupancies) in unlimited area F or S Occupancy buildings.

Due to the special hazards involved, Hazardous Occupancy buildings have many unique fire- and life-safety requirements. Be sure to consult applicable codes at the earliest stages of design.

Excess Frontage

If more than 25% of a building perimeter fronts a street or open space at least 20 ft (6.1 m) wide, the area in the table on these two pages may be increased. For example, to determine the added area for a building with 60% of its perimeter fronting a space 24 ft wide:

1. Determine the excess frontage: 60% – 25% = 35% excess frontage

2. From the following table, read the area increase for each percent of excess frontage: 0.80

3. Calculate the area increase: 0.80 × 35% = 28%

OCCUPANCY H-2: HIGH-HAZARD, ACCELERATED BURNING

		Noncombustible							
CONSTRUCTION TYPE		**3-Hour (page 386)**		**2-Hour (page 386)**		**1-Hour (page 387)**		**Unprotected (page 387)**	
IBC NOMENCLATURE		**Type I-A**		**Type I-B**		**Type II-A**		**Type II-B**	
		Spr	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**
MAXIMUM HEIGHT IN FEET		UH	75′[a]	160′	75′[a]	65′	65′	55′	55′
HEIGHT IN STORIES ABOVE GRADE AND MAXIMUM AREA IN SQ FT FOR ALL FLOORS	UH	63,000	63,000						
	12	63,000	63,000						
	11	63,000	63,000						
	10	63,000	63,000						
	9	63,000	63,000						
	8	63,000	63,000						
	7	63,000	63,000						
	6	63,000	63,000						
	5	63,000	63,000						
	4	63,000	63,000						
	3	63,000	63,000	49,500	49,500				
	2	42,000	42,000	33,000	33,000	22,000	22,000		
	1	21,000	21,000	16,500	16,500	11,000	11,000	7,000	7,000
MAXIMUM AREA IN SQ FT FOR ANY SINGLE FLOOR OF A MULTISTORY BUILDING		21,000	21,000	16,500	16,500	11,000	11,000	7,000	7,000

Each number in the table represents the maximum total area in square feet for all floors for a building of the indicated story height.

[a]Height is measured from the lowest level of firefighter access to highest occupied floor.

Key to Abbreviations

UA	Unlimited area	Spr	With sprinkler system throughout the building
UH	Unlimited height	Unspr	Without a fully sprinklered building
NP	Not permitted		

Width of Frontage	Area Increase for Each Percent of Excess Frontage[a]
20′ (6.1 m)	0.67
22′ (6.7 m)	0.73
24′ (7.3 m)	0.80
26′ (7.9 m)	0.87
28′ (8.5 m)	0.93
30′ (9.1 m) or wider	1.00

[a]Intermediate values may be interpolated.

4. To find the added area for one floor for any High-Hazard (other than H-1) Occupancy building, read the lowest figure in the column for your construction type and multiply this figure by the area increase calculated in the previous step. Continuing the example, assuming an H-2 Occupancy Type I-A building, the added area per floor would be 28% × 21,000 sq ft = 8550 sq ft. For a two-story building, the added area would be twice this amount, or 17,100 sq ft, and for a building three or more stories in height, 3 times this amount, or 25,650 sq ft.

Measurements

Height is measured from the average finished ground level adjoining the building to the average level of the highest roof. Floor area is measured within exterior walls or exterior walls and fire walls, exclusive of courtyards. Basements, where permitted, are not included in area calculations, provided that their area does not exceed the area permitted for a one-story building.

$$1\,\text{ft} = 304.8\,\text{mm}, 1\,\text{sq ft} = 0.0929\,\text{m}^2$$

Further Information

Occupancy classifications: page 6.
Mixed-use buildings: page 374.
Which code to consult: pages 5–6.

Mixed Combustible/Noncombustible												Combustible				
Ordinary				Mass Timber & Heavy Timber								Wood Light Frame				
1-Hour (page 387)		Unprotected (page 387)		Mass Timber (page 388)						Heavy Timber (page 388)		1-Hour (page 391)		Unprotected (page 391)		
Type III-A		Type III-B		Type IV-A		Type IV-B		Type IV-C		Type IV-HT		Type V-A		Type V-B		
Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	
65′	65′	55′	55′	120′	75′[a]	90′	75′[a]	65′	65′	65′	65′	55′	55′	40′	40′	
																UH
																12
																11
																10
																9
																8
																7
																6
																5
																4
																3
19,000	19,000			21,000		21,000		21,000		21,000						2
9,500	9,500	7,000	7,000	10,500	10,500	10,500	10,500	10,500	10,500	10,500	10,500	7,500	7,500	3,000	3,000	1
9,500	9,500	7,000	7,000	10,500	10,500	10,500	10,500	10,500	10,500	10,500	10,500	7,500	7,500	3,000	3,000	

This table was compiled from information contained in the International Building Code 2021. It does not represent an official interpretation by the organization that issues this code.

OCCUPANCY H-3: HIGH-HAZARD, COMBUSTIBLES

Special Requirements

All H-3 *fire areas* must be sprinklered. For additional sprinkler requirements, see page 380.

In mixed-occupancy buildings, H-3 Occupancies must be Separated with 1- to 3-hour fire-resistance rated assemblies from the other Occupancies involved. Accessory and Nonseparated occupancy treatments are not permitted (see pages 374–375). In mixed-occupancy buildings, at least 25% of the perimeter of the H-3 Occupancy must be an exterior wall.

With greater quantities of hazardous material stored, separations of 50 ft (15.2 m) or more from other buildings and public ways are required. Some H-3 Occupancy buildings are restricted solely to the H-3 use, limited to one story in height, and not permitted to include basements, crawlspaces, or other underfloor areas. Certain H-3 Occupancies of limited area and configuration are permitted to be included (as Separated Occupancies) in unlimited area F or S Occupancy buildings.

Due to the special hazards involved, Hazardous Occupancy buildings have many unique fire- and life-safety requirements. Be sure to consult applicable codes at the earliest stages of design.

Excess Frontage

See page 416 for an explanation of applying excess frontage to allowable area increases in High-Hazard Occupancy buildings.

Measurements

Height is measured from the average finished ground level adjoining the building to the average level of the highest roof. Floor area is measured within exterior walls or exterior walls and fire walls, exclusive of courtyards. Basements, where permitted, are not included in area calculations, provided that their area does not exceed the area permitted for a one-story building.

$$1\,\text{ft} = 304.8\,\text{mm}, 1\,\text{sq ft} = 0.0929\,\text{m}^2$$

OCCUPANCY H-3: HIGH-HAZARD, COMBUSTIBLES

	Noncombustible							
CONSTRUCTION TYPE	**3-Hour (page 386)**		**2-Hour (page 386)**		**1-Hour (page 387)**		**Unprotected (page 387)**	
IBC NOMENCLATURE	**Type I-A**		**Type I-B**		**Type II-A**		**Type II-B**	
	Spr	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**
MAXIMUM HEIGHT IN FEET	UH	75′[a]	160′	75′[a]	65′	65′	55′	55′
HEIGHT IN STORIES ABOVE GRADE AND MAXIMUM AREA IN SQ FT FOR ALL FLOORS								
UH	UA	UA						
12								
11								
10								
9								
8								
7								
6			180,000	180,000				
5			180,000	180,000				
4			180,000	180,000	79,500	79,500		
3			180,000	180,000	79,500	79,500		
2			120,000	120,000	53,000	53,000	28,000	28,000
1			60,000	60,000	26,500	26,500	14,000	14,000
MAXIMUM AREA IN SQ FT FOR ANY SINGLE FLOOR OF A MULTISTORY BUILDING	UA	UA	60,000	60,000	26,500	26,500	14,000	14,000

Each number in the table represents the maximum total area in square feet for all floors for a building of the indicated story height.

[a]Height is measured from the lowest level of firefighter access to highest occupied floor.

Key to Abbreviations

UA	Unlimited area	Spr	With sprinkler system throughout the building
UH	Unlimited height	Unspr	Without a fully sprinklered building
NP	Not permitted		

INTERNATIONAL BUILDING CODE

Further Information

Occupancy classifications: page 6.
Mixed-use buildings: page 374.
Which code to consult: pages 5–6.

	Mixed Combustible/Noncombustible												Combustible				
	Ordinary				Mass Timber & Heavy Timber								Wood Light Frame				
	1-Hour (page 387)		Unprotected (page 387)		Mass Timber (page 388)						Heavy Timber (page 388)		1-Hour (page 391)		Unprotected (page 391)		
	Type III-A		Type III-B		Type IV-A		Type IV-B		Type IV-C		Type IV-HT		Type V-A		Type V-B		
	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	
	65′	65′	55′	55′	120′	75′[a]	90′	75′[a]	65′	65′	65′	65′	50′	50′	40′	40′	
																	UH
																	12
																	11
																	10
																	9
																	8
																	7
																	6
																	5
	52,500	52,500			76,500		76,500		76,500		76,500	76,500					4
	52,500	52,500			76,500	76,500	76,500	76,500	76,500	76,500	76,500	76,500					3
	35,000	35,000	26,000	26,000	51,000	51,000	51,000	51,000	51,000	51,000	51,000	51,000	20,000	20,000			2
	17,500	17,500	13,000	13,000	25,500	25,500	25,500	25,500	25,500	25,500	25,500	25,500	10,000	10,000	5,000	5,000	1
	17,500	17,500	13,000	13,000	25,500	25,500	25,500	25,500	25,500	25,500	25,500	25,500	10,000	10,000	5,000	5,000	

This table was compiled from information contained in the International Building Code 2021. It does not represent an official interpretation by the organization that issues this code.

OCCUPANCY H-4: HIGH-HAZARD, CORROSIVES AND TOXICS

Special Requirements

All H-4 *fire areas* must be sprinklered. For additional sprinkler requirements, see page 380.

In mixed-occupancy buildings, H-4 Occupancies must be Separated with 1- to 3-hour fire-resistance rated assemblies from the other Occupancies involved. Accessory and Nonseparated Occupancy treatments are not permitted (see pages 374–375). Certain H-4 Occupancies of limited area and configuration are permitted to be included (as Separated Occupancies) in unlimited area F or S Occupancy buildings.

Due to the special hazards involved, Hazardous Occupancy buildings have many unique fire- and life-safety requirements. Be sure to consult applicable codes at the earliest stages of design.

Excess Frontage

See page 416 for an explanation of applying excess frontage to allowable area increases in High-Hazard Occupancy buildings.

Measurements

Height is measured from the average finished ground level adjoining the building to the average level of the highest roof. Floor area is measured within exterior walls or exterior walls and fire walls, exclusive of courtyards. Basements are not included in area calculations, provided that their area does not exceed the area permitted for a one-story building.

$$1\,\text{ft} = 304.8\,\text{mm}, 1\,\text{sq ft} = 0.0929\,\text{m}^2$$

Further Information

Occupancy classifications: page 6.
Mixed-use buildings: page 374.
Which code to consult: pages 5–6.

OCCUPANCY H-4: HIGH-HAZARD, CORROSIVES AND TOXICS

		Noncombustible							
CONSTRUCTION TYPE		**3-Hour (page 386)**		**2-Hour (page 386)**		**1-Hour (page 387)**		**Unprotected (page 387)**	
IBC NOMENCLATURE		**Type I-A**		**Type I-B**		**Type II-A**		**Type II-B**	
		Spr	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**
MAXIMUM HEIGHT IN FEET		UH	75′[a]	180′	75′[a]	85′	65′	75′	55′
HEIGHT IN STORIES ABOVE GRADE AND MAXIMUM AREA IN SQ FT FOR ALL FLOORS	UH	UA	UA						
	12								
	11								
	10								
	9								
	8			UA					
	7				UA				
	6					337,500			
	5					337,500	112,500		
	4					337,500	112,500	157,500	
	3					337,500	112,500	157,500	52,500
	2					225,000	75,000	105,000	35,000
	1					150,000	37,500	70,000	17,500
MAXIMUM AREA IN SQ FT FOR ANY SINGLE FLOOR OF A MULTISTORY BUILDING		UA	UA	UA	UA	112,500	37,500	52,500	17,500

Each number in the table represents the maximum total area in square feet for all floors for a building of the indicated story height.

[a]Height is measured from the lowest level of firefighter access to highest occupied floor.

Key to Abbreviations

UA	Unlimited area	Spr	With sprinkler system throughout the building
UH	Unlimited height	Unspr	Without a fully sprinklered building
NP	Not permitted		

Mixed Combustible/Noncombustible												Combustible				
Ordinary				Mass Timber & Heavy Timber								Wood Light Frame				
1-Hour (page 387)		Unprotected (page 387)		Mass Timber (page 388)						Heavy Timber (page 388)		1-Hour (page 391)		Unprotected (page 391)		
Type III-A		Type III-B		Type IV-A		Type IV-B		Type IV-C		Type IV-HT		Type V-A		Type V-B		
Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	
85′	65′	75′	55′	140′	65′	100′	65′	85′	65′	85′	65′	70′	50′	60′	40′	
																UH
																12
																11
																10
																9
				648,000												8
				648,000		486,000										7
256,500				648,000		486,000		364,500		324,000						6
256,500	85,500			648,000	216,000	486,000	162,000	364,500	121,500	324,000	108,000					5
256,500	85,500	157,500		648,000	216,000	486,000	162,000	364,500	121,500	324,000	108,000	162,000				4
256,500	85,500	157,500	52,500	648,000	216,000	486,000	162,000	364,500	121,500	324,000	108,000	162,000	54,000	58,500		3
171,000	57,000	105,000	35,000	432,000	144,000	324,000	108,000	243,000	81,000	216,000	72,000	108,000	36,000	39,000		2
114,000	28,500	70,000	17,500	288,000	72,000	216,000	54,000	162,000	40,500	144,000	36,000	72,000	18,000	26,000	6,500	1
85,500	28,500	52,500	17,500	216,000	72,000	162,000	54,000	121,500	40,500	108,000	36,000	54,000	18,000	19,500	6,500	

This table was compiled from information contained in the International Building Code 2021. It does not represent an official interpretation by the organization that issues this code.

OCCUPANCY H-5: HIGH-HAZARD, HAZARDOUS PRODUCTION MATERIALS

Special Requirements

A sprinkler system is required throughout buildings containing, in whole or in part, an H-5 Occupancy.

In mixed-occupancy buildings, H-5 Occupancies must be Separated with 1- to 2-hour fire-resistance rated assemblies from the other Occupancies involved. Accessory and Nonseparated Occupancy treatments are not permitted (see pages 374–375).

Due to the special hazards involved, Hazardous Occupancy buildings have many unique fire- and life-safety requirements. Be sure to consult applicable codes at the earliest stages of design.

Excess Frontage

See page 416 for an explanation of applying excess frontage to allowable area increases in High-Hazard Occupancy buildings.

Measurements

Height is measured from the average finished ground level adjoining the building to the average level of the highest roof. Floor area is measured within exterior walls or exterior walls and fire walls, exclusive of courtyards. Basements are not included in area calculations, provided that their area does not exceed the area permitted for a one-story building.

$$1\,\text{ft} = 304.8\,\text{mm}, 1\,\text{sq ft} = 0.0929\,\text{m}^2$$

Further Information

Occupancy classifications: page 6.
Mixed-use buildings: page 374.
Which code to consult: pages 5–6.

OCCUPANCY H-5: HIGH-HAZARD, HAZARDOUS PRODUCTION FACILITIES

		Noncombustible							
CONSTRUCTION TYPE		3-Hour (page 386)		2-Hour (page 386)		1-Hour (page 387)		Unprotected (page 387)	
IBC NOMENCLATURE		Type I-A		Type I-B		Type II-A		Type II-B	
		Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr
MAXIMUM HEIGHT IN FEET		UH		160′		65′		55′	
	UH								
	12								
	11								
	10								
	9								
HEIGHT IN STORIES ABOVE GRADE AND MAXIMUM AREA IN SQ FT FOR ALL FLOORS	8								
	7								
	6								
	5								
	4	UA		UA					
	3					337,500		207,000	
	2					225,000		138,000	
	1		NP		NP	150,000	NP	92,000	NP
MAXIMUM AREA IN SQ FT FOR ANY SINGLE FLOOR OF A MULTISTORY BUILDING		UA		UA		112,500		69,000	

Each number in the table represents the maximum total area in square feet for all floors for a building of the indicated story height.

Key to Abbreviations

UA	Unlimited area	Spr	With sprinkler system throughout the building
UH	Unlimited height	Unspr	Without a fully sprinklered building
NP	Not permitted		

Mixed Combustible/Noncombustible												Combustible				
Ordinary				Mass Timber & Heavy Timber								Wood Light Frame				
1-Hour (page 387)		Unprotected (page 387)		Mass Timber (page 388)						Heavy Timber (page 388)		1-Hour (page 391)		Unprotected (page 391)		
Type III-A		Type III-B		Type IV-A		Type IV-B		Type IV-C		Type IV-HT		Type V-A		Type V-B		
Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	
65′		55′		120′		90′		65′		65′		50′		40′		
																UH
																12
																11
																10
																9
																8
																7
																6
																5
																4
256,500		171,000		648,000		486,000		364,500		324,000		162,000				3
171,000		114,000		432,000		324,000		243,000		216,000		108,000		54,000		2
114,000	NP	76,000	NP	288,000	NP	216,000	NP	162,000	NP	144,000	NP	72,000	NP	36,000	NP	1
85,500		57,000		216,000		162,000		121,500		108,000		54,000		27,000		

This table was compiled from information contained in the International Building Code 2021. It does not represent an official interpretation by the organization that issues this code.

OCCUPANCY I-1: INSTITUTIONAL, RESIDENTIAL CARE

Sprinklers

A sprinkler system is required throughout *entire buildings* containing, in whole or in part, an I-1 Occupancy. In the chart on these two facing pages, read from the columns labeled *Spr-1* for buildings in which residents are capable of unassisted self-evacuation in the event of a building emergency. Read from the columns labeled *Spr-2* if residents are not fully capable of self-preservation and may need assistance from facility staff in the event of a building emergency.

In I-1 Occupancy buildings of limited height, in which residents are capable of unassisted evacuation in the event of an emergency, lower-cost NFPA 13R sprinkler systems (see page 262) may be used. Such buildings may be no taller than four stories, with the highest occupied floor no more than 30 ft (9.1 m) above the lowest level of firefighter access. When reading from the height and area table, allowable area for single-floor buildings should be reduced to one-quarter of the values indicated in the columns labeled *Spr-1* and allowable areas for buildings two to four stories in height should be reduced to one-third the values indicated.

Resident Evacuation Assistance Conditions

Where residents in I-1 Occupancy buildings are not fully capable of independent self-preservation in the case of a building emergency, floors with an occupant load greater than 50 or used by residents for sleeping or treatment must be subdivided by smoke barriers into at least two separate refuge areas with independent means of egress (see page 283).

Excess Frontage

If more than 25% of a building perimeter fronts a street or open space at least 20 ft (6.1 m) wide, the area in the table on these two pages may be increased. For example, to determine the added area for a building with 60% of its perimeter fronting a space 24 ft wide:

1. Determine the excess frontage: 60% – 25% = 35% excess frontage

2. From the following table, read the area increase for each percent of excess frontage: 0.80

OCCUPANCY I-1: INSTITUTIONAL, RESIDENTIAL CARE

		Noncombustible							
CONSTRUCTION TYPE		**3-Hour (page 386)**		**2-Hour (page 386)**		**1-Hour (page 387)**		**Unprotected (page 387)**	
IBC NOMENCLATURE		**Type I-A**		**Type I-B**		**Type II-A**		**Type II-B**	
		Spr-1	**Spr-2**	**Spr-1**	**Spr-2**	**Spr-1**	**Spr-2**	**Spr-1**	**Spr-2**
MAXIMUM HEIGHT IN FEET		UH	UH	180’	180’	85’	85’	75’	55’
HEIGHT IN STORIES ABOVE GRADE AND MAXIMUM AREA IN SQ FT FOR ALL FLOORS	UH	UA	UA						
	12								
	11								
	10			495,000	495,000				
	9			495,000	495,000				
	8			495,000	495,000				
	7			495,000	495,000				
	6			495,000	495,000				
	5			495,000	495,000	171,000	171,000		
	4			495,000	495,000	171,000	171,000	90,000	
	3			495,000	495,000	171,000	171,000	90,000	90,000
	2			330,000	330,000	114,000	114,000	60,000	60,000
	1			220,000	220,000	76,000	76,000	40,000	40,000
MAXIMUM AREA IN SQ FT FOR ANY SINGLE FLOOR OF A MULTISTORY BUILDING		UA	UA	165,000	165,000	57,000	57,000	30,000	30,000

Each number in the table represents the maximum total area in square feet for all floors for a building of the indicated story height.

Key to Abbreviations

UA	Unlimited area	Spr-1	Fully sprinklered building, with residents capable of unassisted self-evacuation
UH	Unlimited height	Spr-2	Fully sprinklered building, with residents requiring assistance during evacuation
NP	Not permitted		

Width of Frontage	Area Increase for Each Percent of Excess Frontage[a]
20′ (6.1 m)	0.67
22′ (6.7 m)	0.73
24′ (7.3 m)	0.80
26′ (7.9 m)	0.87
28′ (8.5 m)	0.93
30′ (9.1 m) or wider	1.00

[a]Intermediate values may be interpolated.

3. Calculate the area increase: 0.80 × 35% = 28%

4. For I-1 Occupancies, the added area for excess frontage is determined using lower area amounts than listed in the table on these two facing pages. To find the added area for one floor, read the lowest figure in the unsprinklered column for your construction type, divide the area indicated there by 3, and multiply this figure by the area increase calculated in the previous step. Continuing the example, assuming a Type II-B building, with the excess frontage described above, the added area per floor would be 28% × (30,000 sq ft ÷ 3) = 2800 sq ft. For a two-story building, the added area would be twice this amount, or 5600 sq ft, and for a building three or more stories in height, 3 times this amount, or 8400 sq ft.

Measurements

Height is measured from the average finished ground level adjoining the building to the average level of the highest roof. Floor area is measured within exterior walls or exterior walls and fire walls, exclusive of courtyards. Basements are not included in area calculations, provided that their area does not exceed the area permitted for a one-story building.

$$1\,\text{ft} = 304.8\,\text{mm}, 1\,\text{sq ft} = 0.0929\,\text{m}^2$$

Further Information

Occupancy classifications: page 6.
Mixed-use buildings: page 374.
Which code to consult: pages 5–6.

Mixed Combustible/Noncombustible												Combustible				
Ordinary				Mass Timber & Heavy Timber								Wood Light Frame				
1-Hour (page 387)		Unprotected (page 387)		Mass Timber (page 388)						Heavy Timber (page 388)		1-Hour (page 391)		Unprotected (page 391)		
Type III-A		Type III-B		Type IV-A		Type IV-B		Type IV-C		Type IV-HT		Type V-A		Type V-B		
Spr-1	Spr-2	Spr-1	Spr-2	Spr-1	Spr-2	Spr-1	Spr-2	Spr-1	Spr-2	Spr-1	Spr-2	Spr-1	Spr-2	Spr-1	Spr-2	
85’	65’	75’	55’	180’	65’	120’	65’	85’	65’	85’	65’	70’	50’	60’	40’	
																UH
																12
																11
				486,000	486,000											10
				486,000	486,000											9
				486,000	486,000											8
				486,000	486,000	324,000										7
				486,000	486,000	324,000	324,000									6
148,500				486,000	486,000	324,000	324,000	162,000		162,000						5
148,500	148,500	90,000		486,000	486,000	324,000	324,000	162,000	162,000	162,000	162,000	94,500				4
148,500	148,500	90,000	90,000	486,000	486,000	324,000	324,000	162,000	162,000	162,000	162,000	94,500	94,500	40,500		3
99,000	99,000	60,000	60,000	324,000	324,000	216,000	216,000	108,000	108,000	108,000	108,000	63,000	63,000	27,000	27,000	2
66,000	66,000	40,000	40,000	216,000	216,000	144,000	144,000	72,000	72,000	72,000	72,000	42,000	42,000	18,000	18,000	1
49,500	49,500	30,000	30,000	162,000	162,000	108,000	108,000	54,000	54,000	54,000	54,000	31,500	31,500	13,500	13,500	

This table was compiled from information contained in the International Building Code 2021. It does not represent an official interpretation by the organization that issues this code.

OCCUPANCY I-2: INSTITUTIONAL, MEDICAL, AND CUSTODIAL CARE

Special Requirements

A sprinkler system is required throughout *entire buildings* containing, in whole or in part, an I-2 Occupancy.

In all I-2 Occupancies, floors with an occupant load greater than 50 or used by patients for sleeping or treatment must be subdivided by smoke barriers into at least two separate refuge areas with independent means of egress (see page 283).

Excess Frontage

If more than 25% of a building perimeter fronts a street or open space at least 20 ft (6.1 m) wide, the area in the table on these two pages may be increased. For example, to determine the added area for a building with 60% of its perimeter fronting a space 24 ft wide:

1. Determine the excess frontage: 60% – 25% = 35% excess frontage

2. From the following table, read the area increase for each percent of excess frontage: 0.80

Width of Frontage	Area Increase for Each Percent of Excess Frontage[a]
20′ (6.1 m)	0.67
22′ (6.7 m)	0.73
24′ (7.3 m)	0.80
26′ (7.9 m)	0.87
28′ (8.5 m)	0.93
30′ (9.1 m) or wider	1.00

[a]Intermediate values may be interpolated.

3. Calculate the area increase: $0.80 \times 35\% = 28\%$

4. For all Institutional Occupancies other than I-1, the added area for excess frontage is determined using unsprinklered area allowances. To find the added area for one floor, read the bottom figure in the unsprinklered column for your construction type and multiply this figure by the area increase calculated in the previous step. Continuing the example, assuming an I-2 Occupancy Type II-A building, sprinklered, with the excess frontage described above, the added area per floor would be 28% × 15,000 sq ft = 4200 sq ft. For a two-story building, the added area would be twice this amount, or 8400 sq ft, and for a building three or more stories in height, 3 times this amount, or 12,600 sq ft.

OCCUPANCY I-2: INSTITUTIONAL, MEDICAL AND CUSTODIAL CARE

		Noncombustible							
CONSTRUCTION TYPE		**3-Hour (page 386)**		**2-Hour (page 386)**		**1-Hour (page 387)**		**Unprotected (page 387)**	
IBC NOMENCLATURE		**Type I-A**		**Type I-B**		**Type II-A**		**Type II-B**	
		Spr	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**
MAXIMUM HEIGHT IN FEET		UH		180′		85′		55′	
HEIGHT IN STORIES ABOVE GRADE AND MAXIMUM AREA IN SQ FT FOR ALL FLOORS	UH	UA							
	12								
	11								
	10								
	9								
	8								
	7								
	6								
	5			UA					
	4								
	3					135,000			
	2					90,000			
	1		NP		NP	60,000	NP	44,000	NP
MAXIMUM AREA IN SQ FT FOR ANY SINGLE FLOOR OF A MULTISTORY BUILDING		UA		UA		45,000	15,000[a]		

Each number in the table represents the maximum total area in square feet for all floors for a building of the indicated story height.

[a]These figures are used in excess frontage calculations.

Key to Abbreviations

UA	Unlimited area	Spr	With sprinkler system throughout the building
UH	Unlimited height	Unspr	Without sprinkler system throughout the building
NP	Not permitted		

Measurements

Height is measured from the average finished ground level adjoining the building to the average level of the highest roof. Floor area is measured within exterior walls or exterior walls and fire walls, exclusive of courtyards. Basements are not included in area calculations, provided that their area does not exceed the area permitted for a one-story building.

$$1\,\text{ft} = 304.8\,\text{mm}, 1\,\text{sq ft} = 0.0929\,\text{m}^2$$

Further Information

Occupancy classifications: page 6.
Mixed-use buildings: page 374.
Which code to consult: pages 5–6.

Mixed Combustible/Noncombustible												Combustible				
Ordinary				Mass Timber & Heavy Timber								Wood Light Frame				
1-Hour (page 387)		Unprotected (page 387)		Mass Timber (page 388)						Heavy Timber (page 388)		1-Hour (page 391)		Unprotected (page 391)		
Type III-A		Type III-B		Type IV-A		Type IV-B		Type IV-C		Type IV-HT		Type V-A		Type V-B		
Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	
65′		55′		65′		65′		65′		65′		50′				
																UH
																12
																11
																10
																9
																8
				324,000												7
				324,000												6
				324,000		216,000										5
				324,000		216,000										4
				324,000		216,000										3
				216,000		144,000										2
48,000	NP	NP	NP	144,000	NP	96,000	NP	48,000	NP	48,000	NP	38,000	NP	NP	NP	1
				108,000	36,000[a]	72,000	2,4000[a]		12,000[a]		12,000[a]		9,500[a]			

This table was compiled from information contained in the International Building Code 2021. It does not represent an official interpretation by the organization that issues this code.

OCCUPANCY I-3: INSTITUTIONAL, DETENTION AND SECURITY

Special Requirements

A sprinkler system is required throughout *entire buildings* containing, in whole or in part, an I-3 Occupancy.

In all I-3 Occupancies, floors with an occupant load greater than 50 or used by residents for sleeping or treatment must be subdivided by smoke barriers into at least two separate refuge areas with independent means of egress (see page 283). Alternatively, residents may be provided with direct exit access to a public way, separate building, or secured yard or court.

Excess Frontage

See page 426 for an explanation of applying excess frontage to allowable area increases in Institutional Occupancy buildings.

Measurements

Height is measured from the average finished ground level adjoining the building to the average level of the highest roof. Floor area is measured within exterior walls or exterior walls and fire walls, exclusive of courtyards. Basements are not included in area calculations, provided that their area does not exceed the area permitted for a one-story building.

$1\,ft = 304.8\,mm, 1\,sq\,ft = 0.0929\,m^2$

Further Information

Occupancy classifications: page 6.
Mixed-use buildings: page 374.
Which code to consult: pages 5–6.

OCCUPANCY I-3: INSTITUTIONAL, DETENTION AND SECURITY

		Noncombustible							
CONSTRUCTION TYPE		**3-Hour (page 386)**		**2-Hour (page 386)**		**1-Hour (page 387)**		**Unprotected (page 387)**	
IBC NOMENCLATURE		**Type I-A**		**Type I-B**		**Type II-A**		**Type II-B**	
		Spr	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**
MAXIMUM HEIGHT IN FEET		UH		180′		85′		75′	
HEIGHT IN STORIES ABOVE GRADE AND MAXIMUM AREA IN SQ FT FOR ALL FLOORS	UH	UA							
	12								
	11								
	10								
	9								
	8								
	7								
	6								
	5			UA					
	4								
	3					135,000			
	2					90,000		60,000	
	1		NP		NP	60,000	NP	40,000	NP
MAXIMUM AREA IN SQ FT FOR ANY SINGLE FLOOR OF A MULTISTORY BUILDING		UA		UA		45,000	15,000[a]	30,000	10,000[a]

Each number in the table represents the maximum total area in square feet for all floors for a building of the indicated story height.

[a]These figures are used in excess frontage calculations.

Key to Abbreviations

UA	Unlimited area	Spr	With sprinkler system throughout the building
UH	Unlimited height	Unspr	Without a fully sprinklered building
NP	Not permitted		

Mixed Combustible/Noncombustible												Combustible				
Ordinary				Mass Timber & Heavy Timber								Wood Light Frame				
1-Hour (page 387)		Unprotected (page 387)		Mass Timber (page 388)						Heavy Timber (page 388)		1-Hour (page 391)		Unprotected (page 391)		
Type III-A		Type III-B		Type IV-A		Type IV-B		Type IV-C		Type IV-HT		Type V-A		Type V-B		
Spr	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**	
85′		75′		180′		120′		85′		85′		70′		60′		
																UH
																12
																11
																10
																9
																8
				324,000												7
				324,000												6
				324,000		216,000										5
				324,000		216,000										4
94,500				324,000		216,000		108,000		108,000		67,500				3
63,000		45,000		216,000		144,000		72,000		72,000		45,000		30,000		2
42,000	NP	30,000	NP	144,000	NP	96,000	NP	48,000	NP	48,000	NP	30,000	NP	20,000	NP	1
31,500	10,500[a]	22,500	7,500[a]	108,000	3,6000[a]	72,000	24,000[a]	36,000	12,000[a]	36,000	12,000[a]	22,500	7,500[a]	15,000	5,000[a]	

This table was compiled from information contained in the International Building Code 2021. It does not represent an official interpretation by the organization that issues this code.

OCCUPANCY I-4: INSTITUTIONAL, DAY CARE

Sprinklers

If an I-4 Occupancy day care facility is on the level of exit discharge (the ground floor or other level from which occupants exit the building) and every room where care is provided has a direct exit to the exterior, no sprinklers are required. For other such facilities on the level of exit discharge, that level and any levels below (not including open parking) must be sprinklered. When such a facility occurs on any building floor other than the level of exit discharge, the following must be sprinklered:

- The day care facility floor
- The level of exit discharge floor
- All floors between the level of exit discharge and the day care facility floor
- All floors below the level of exit discharge, except open parking below the level of exit discharge

For additional sprinkler requirements, see page 380.

Excess Frontage

See page 426 for an explanation of applying excess frontage to allowable area increases in Institutional occupancy buildings.

Measurements

Height is measured from the average finished ground level adjoining the building to the average level of the highest roof. Floor area is

OCCUPANCY I-4: INSTITUTIONAL, DAY CARE

		Noncombustible							
CONSTRUCTION TYPE		**3-Hour (page 386)**		**2-Hour (page 386)**		**1-Hour (page 387)**		**Unprotected (page 387)**	
IBC NOMENCLATURE		**Type I-A**		**Type I-B**		**Type II-A**		**Type II-B**	
		Spr	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**
MAXIMUM HEIGHT IN FEET		UH	75′[a]	180′	75′[a]	85′	65′	75′	55′
HEIGHT IN STORIES ABOVE GRADE AND MAXIMUM AREA IN SQ FT FOR ALL FLOORS	UH	UA	UA						
	12								
	11								
	10								
	9								
	8								
	7								
	6			544,500					
	5			544,500	181,500				
	4			544,500	181,500	238,500			
	3			544,500	181,500	238,500	79,500	117,000	
	2			363,000	121,000	159,000	53,000	78,000	26,000
	1			242,000	60,500	106,000	26,500	52,000	13,000
MAXIMUM AREA IN SQ FT FOR ANY SINGLE FLOOR OF A MULTISTORY BUILDING		UA	UA	181,500	60,500	79,500	26,500	39,000	13,000

Each number in the table represents the maximum total area in square feet for all floors for a building of the indicated story height.

[a]Height is measured from the lowest level of firefighter access to highest occupied floor.

Key to Abbreviations

UA	Unlimited area	Spr	With sprinkler system throughout the building
UH	Unlimited height	Unspr	Without a fully sprinklered building
NP	Not permitted		

measured within exterior walls or exterior walls and fire walls, exclusive of courtyards. Basements are not included in area calculations, provided that their area does not exceed the area permitted for a one-story building.

$$1\,\mathrm{ft} = 304.8\,\mathrm{mm}, 1\,\mathrm{sq\,ft} = 0.0929\,\mathrm{m}^2$$

Further Information

Occupancy classifications: page 6.
Mixed-use buildings: page 374.
Which code to consult: pages 5–6.

Mixed Combustible/Noncombustible												Combustible				
Ordinary				Mass Timber & Heavy Timber								Wood Light Frame				
1-Hour (page 387)		Unprotected (page 387)		Mass Timber (page 388)						Heavy Timber (page 388)		1-Hour (page 391)		Unprotected (page 391)		
Type III-A		Type III-B		Type IV-A		Type IV-B		Type IV-C		Type IV-HT		Type V-A		Type V-B		
Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	
85′	65′	75′	55′	180′	65′	120′	65′	85′	65′	85′	65′	70′	50′	60′	40′	
																UH
																12
																11
																10
				688,500												9
				688,500												8
				688,500												7
				688,500		459,000										6
				688,500		459,000										5
211,500				688,500		459,000		229,500		229,500						4
211,500	70,500	117,000		688,500	229,500	459,000	153,000	229,500	76,500	229,500	76,500					3
141,000	47,000	78,000	26,000	459,000	153,000	306,000	102,000	153,000	51,000	153,000	51,000	111,000		54,000		2
94,000	23,500	52,000	13,000	306,000	76,500	204,000	51,000	102,000	25,500	102,000	25,500	74,000	18,500	36,000	9,000	1
70,500	23,500	39,000	13,000	229,500	76,500	153,000	51,000	76,500	25,500	76,500	25,500	55,500	18,500	27,000	9,000	

This table was compiled from information contained in the International Building Code 2021. It does not represent an official interpretation by the organization that issues this code.

OCCUPANCY M: MERCANTILE

Sprinklers

In addition to the requirements indicated in the table on these two facing pages, a sprinkler system is required throughout *entire buildings* meeting any of the following conditions:

- Containing an M Occupancy fire area exceeding 12,000 sq ft (1115 m²)
- Containing an M Occupancy fire area located four or more stories above grade
- Containing multiple M Occupancy fire areas, including mezzanines, that in total exceed 24,000 sq ft (2230 m²) in area
- Where merchandise is stored in high-piled or rack storage arrays

A sprinkler system is required for all M Occupancy *fire areas* exceeding 5,000 sq ft (464 m²) and used for the display or sale of upholstered furniture or mattresses. For additional sprinkler requirements, see page 380.

Unlimited Area Buildings

Fully sprinklered one- or two-story M Occupancy buildings may be of unlimited area when the building is surrounded on all sides by streets or open space not less than 40 to 60 ft (12.2 to 18.3 m) in width.

Mall buildings enclosing multiple retail, entertainment, and related facilities are permitted to be of unlimited area, provided that they are fully sprinklered, no more than three stories in height, and of any Construction Type except Wood Light Frame. In such buildings, tenant spaces must be separated from each other by 1-hour fire-resistance-rated partitions, but no separation is required between the tenant and the common mall areas.

Mall anchor buildings, fully sprinklered and complying with the same height and Construction Type limits as above may also be of unlimited area. They must be separated from the mall by 2-hour fire-resistance-rated fire barriers. Unlimited area mall buildings and anchor buildings must be surrounded on all sides by streets or open space, 40 to 60 ft (12.2 to 18.3 m) in width.

Excess Frontage

If more than 25% of a building perimeter fronts a street or open space at least 20 ft (6.1 m) wide, the

OCCUPANCY M: MERCANTILE

		Noncombustible							
CONSTRUCTION TYPE		**3-Hour (page 386)**		**2-Hour (page 386)**		**1-Hour (page 387)**		**Unprotected (page 387)**	
IBC NOMENCLATURE		**Type I-A**		**Type I-B**		**Type II-A**		**Type II-B**	
		Spr	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**
MAXIMUM HEIGHT IN FEET		UH	75′[a]	180′	75′[a]	85′	65′	75′	55′
HEIGHT IN STORIES ABOVE GRADE AND MAXIMUM AREA IN SQ FT FOR ALL FLOORS	UH	UA	UA						
	12			UA					
	11				UA				
	10								
	9								
	8								
	7								
	6								
	5					193,500			
	4					193,500	64,500		
	3					193,500	64,500	112,500	
	2					129,000	43,000	75,000	25,000
	1					86,000	21,500	50,000	12,500
MAXIMUM AREA IN SQ FT FOR ANY SINGLE FLOOR OF A MULTISTORY BUILDING		UA	UA	UA	UA	64,500	21,500	37,500	12,500

Each number in the table represents the maximum total area in square feet for all floors for a building of the indicated story height.

[a]Height is measured from the lowest level of firefighter access to highest occupied floor.

Key to Abbreviations

UA	Unlimited area	Spr	With sprinkler system throughout the building
UH	Unlimited height	Unspr	Without a fully sprinklered building
NP	Not permitted		

area in the table on these two pages may be increased. For example, to determine the added area for a building with 60% of its perimeter fronting a space 24 ft wide:

1. Determine the excess frontage: 60% – 25% = 35% excess frontage

2. From the following table, read the area increase for each percent of excess frontage: 0.80

Width of Frontage	Area Increase for Each Percent of Excess Frontage[a]
20′ (6.1 m)	0.67
22′ (6.7 m)	0.73
24′ (7.3 m)	0.80
26′ (7.9 m)	0.87
28′ (8.5 m)	0.93
30′ (9.1 m) or wider	1.00

[a]Intermediate values may be interpolated.

3. Calculate the area increase: 0.80 × 35% = 28%

4. The added area for excess frontage is determined using unsprinklered area allowances. To find the added area for one floor, read the lowest figure in the unsprinklered column for your construction type and multiply this figure by the area increase calculated in the previous step. Continuing the example, assuming a Type III-A building, sprinklered or unsprinklered with the excess frontage described above, the added area per floor would be 28% × 18,500 sq ft = 4625 sq ft. For a two-story building, the added area would be twice this amount, or 9250 sq ft, and for a building three or more stories in height, 3 times this amount, or 13,875 sq ft.

Measurements

Height is measured from the average finished ground level adjoining the building to the average level of the highest roof. Floor area is measured within exterior walls or exterior walls and fire walls, exclusive of courtyards. Basements are not included in area calculations, provided that their area does not exceed the area permitted for a one-story building.

$1\,ft = 304.8\,mm, 1\,sq\,ft = 0.0929\,m^2$

Further Information

Occupancy classifications: page 6.
Mixed-use buildings: page 374.
Which code to consult: pages 5–6.

Mixed Combustible/Noncombustible												Combustible				
Ordinary				Mass Timber & Heavy Timber								Wood Light Frame				
1-Hour (page 387)		Unprotected (page 387)		Mass Timber (page 388)						Heavy Timber (page 388)		1-Hour (page 391)		Unprotected (page 391)		
Type III-A		Type III-B		Type IV-A		Type IV-B		Type IV-C		Type IV-HT		Type V-A		Type V-B		
Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	
85′	65′	75′	55′	270′	65′	180′	65′	85′	65′	85′	65′	70′	50′	60′	40′	UH
				553,500												12
				553,500												11
				553,500												10
				553,500												9
				553,500		369,000										8
				553,500		369,000										7
				553,500		369,000		230,625								6
166,500				553,500		369,000		230,625		184,500						5
166,500	55,500			553,500	184,500	369,000	123,000	230,625		184,500	61,500	126,000				4
166,500	55,500	112,500		553,500	184,500	369,000	123,000	230,625	79,875	184,500	61,500	126,000	55,500			3
111,000	37,000	75,000	25,000	369,000	123,000	246,000	82,000	153,750	53,250	123,000	41,000	84,000	37,000	54,000		2
74,000	18,500	50,000	12,500	246,000	61,500	164,000	41,000	102,500	26,625	82,000	20,500	56,000	18,500	36,000	9,000	1
55,500	18,500	37,500	12,500	184,500	61,500	123,000	41,000	76,875	26,625	61,500	20,500	42,000	14,000	27,000	9,000	

This table was compiled from information contained in the International Building Code 2021. It does not represent an official interpretation by the organization that issues this code.

OCCUPANCY R-1: RESIDENTIAL, HOTELS AND MOTELS

Sprinklers

A sprinkler system is required throughout *entire buildings* containing, in whole or in part, an R-1 Occupancy.

In buildings not more than four stories and with the highest story not more than 30 ft (9.1 m) above the lowest level of firefighter access, less expensive residential class NFPA 13R sprinkler systems (page 262) are permitted as an alternative to commercial grade NFPA 13 systems. For such buildings, read the table on these two facing pages from the columns labeled *Res Spr*.

Special Height Exceptions

R-1 Occupancy buildings of 1-Hour Ordinary Construction may be up to six stories and 95 ft (29.0 m) in height, provided that the floor assembly separating basement areas from floors above has a fire-resistance rating of at least 3 hours and the building contains continuous vertical 2-hour-rated fire walls that subdivide all floors into areas not exceeding 3000 sq ft (279 m^2).

R-1 Occupancy buildings of 1-Hour Noncombustible Construction may be up to nine stories and 100 ft (30.4 m) in height, provided that the floor assembly separating basement areas from floors above has a fire-resistance rating of at least 1½ hours, exits are separated from the rest of the building by 2-hour-rated fire walls, and the building is separated from other buildings and lot lines by a distance of at least 50 ft (15.2 m).

Where an R-1 Occupancy is constructed over a single-story at-grade S-2 Occupancy parking garage, the parking garage level is omitted when counting the number of stories. The floor above the parking garage must have a 1- or 2-hour fire-resistance rating.

Excess Frontage

If more than 25% of a building perimeter fronts a street or open space at least 20 ft (6.1 m) wide, the area in the table on these two pages may be increased. For example, to determine the added area for a building with 60% of its perimeter fronting a space 24 ft wide:

OCCUPANCY R-1: RESIDENTIAL, HOTELS AND MOTELS

		Noncombustible							
CONSTRUCTION TYPE		3-Hour (page 386)		2-Hour (page 386)		1-Hour (page 387)		Unprotected (page 387)	
IBC NOMENCLATURE		Type I-A		Type I-B		Type II-A		Type II-B	
		Spr	Res Spr	Spr	Res Spr	Spr	Res Spr	Spr	Res Spr
MAXIMUM HEIGHT IN FEET		UH	30′[a]	180′	30′[a]	85′	30′[a]	75′	30′[a]
HEIGHT IN STORIES ABOVE GRADE AND MAXIMUM AREA IN SQ FT FOR ALL FLOORS	UH	UA							
	12			UA					
	11								
	10								
	9								
	8								
	7								
	6								
	5					216,000		144,000	
	4		UA		UA	216,000	72,000	144,000	48,000
	3					216,000	72,000	144,000	48,000
	2					144,000	48,000	96,000	32,000
	1					96,000	24,000	64,000	16,000
MAXIMUM AREA IN SQ FT FOR ANY SINGLE FLOOR OF A MULTISTORY BUILDING		UA	UA	UA	UA	72,000	24,000	48,000	16,000

Each number in the table represents the maximum total area in square feet for all floors for a building of the indicated story height.

[a]Height is measured from the lowest level of firefighter access to highest occupied floor.

Key to Abbreviations

UA	Unlimited area	Spr	With NFPA 13 sprinkler system throughout the building
UH	Unlimited height	Res Spr	Residential class NFPA 13R sprinkler system
NP	Not permitted		

1. Determine the excess frontage: 60% – 25% = 35% excess frontage

2. From the following table, read the area increase for each percent of excess frontage: 0.80

Width of Frontage	Area Increase for Each Percent of Excess Frontage[a]
20′ (6.1 m)	0.67
22′ (6.7 m)	0.73
24′ (7.3 m)	0.80
26′ (7.9 m)	0.87
28′ (8.5 m)	0.93
30′ (9.1 m) or wider	1.00

[a]Intermediate values may be interpolated.

3. Calculate the area increase: 0.80 × 35% = 28%

4. For Residential Occupancy buildings, the added area for excess frontage is determined using Residential Sprinkler area allowances. To find the added area for one floor, read the lowest figure in the *Res Spr* column for your construction type and multiply this figure by the area increase calculated in the previous step. Continuing the example, assuming an R-1 Occupancy Type V-A building, sprinklered or unsprinklered with the excess frontage described above, the added area per floor would be 28% × 12,000 sq ft = 3360 sq ft. For a two-story building, the added area would be twice this amount, or 6720 sq ft, and for a building three or more stories in height, 3 times this amount, or 10,080 sq ft.

Measurements

Height is measured from the average finished ground level adjoining the building to the average level of the highest roof. Floor area is measured within exterior walls or exterior walls and fire walls, exclusive of courtyards. Basements are not included in area calculations, provided that their area does not exceed the area permitted for a one-story building.

1 ft = 304.8 mm, 1 sq ft = 0.0929 m²

Mixed Combustible/Noncombustible												Combustible				
Ordinary				Mass Timber & Heavy Timber								Wood Light Frame				
1-Hour (page 387)		Unprotected (page 387)		Mass Timber (page 388)						Heavy Timber (page 388)		1-Hour (page 391)		Unprotected (page 391)		
Type III-A		Type III-B		Type IV-A		Type IV-B		Type IV-C		Type IV-HT		Type V-A		Type V-B		
Spr	Res Spr	Spr	Res Spr	Spr	Res Spr	Spr	Res Spr	Spr	Res Spr	Spr	Res Spr	Spr	Res Spr	Spr	Res Spr	
85′	30′[a]	75′	30′[a]	270′	30′[a]	180′	30′[a]	85′	30′[a]	85′	30′[a]	70′	30′[a]	60′	30′[a]	
				18 stories max												UH
				553,500		369,000										12
				553,500		369,000										11
				553,500		369,000										10
				553,500		369,000										9
				553,500		369,000		230,625								8
				553,500		369,000		230,625								7
				553,500		369,000		230,625								6
216,000		144,000		553,500		369,000		230,625		184,500						5
216,000	72,000	144,000	48,000	553,500	184,500	369,000	123,000	230,625	76,875	184,500	61,500	108,000	36,000			4
216,000	72,000	144,000	48,000	553,500	184,500	369,000	123,000	230,625	76,875	184,500	61,500	108,000	36,000	63,000	21,000	3
144,000	48,000	96,000	32,000	369,000	123,000	246,000	82,000	153,750	51,250	123,000	41,000	72,000	24,000	42,000	14,000	2
96,000	24,000	64,000	16,000	246,000	61,500	164,000	41,000	102,500	25,625	82,000	20,500	48,000	12,000	28,000	7,000	1
72,000	24,000	48,000	16,000	184,500	61,500	123,000	41,000	76,875	25,625	61,500	20,500	36,000	12,000	21,000	7,000	

This table was compiled from information contained in the International Building Code 2021. It does not represent an official interpretation by the organization that issues this code.

OCCUPANCY R-2: RESIDENTIAL, MULTIFAMILY

Sprinklers

A sprinkler system is required throughout *entire buildings* containing, in whole or in part, an R-2 Occupancy.

In buildings not more than four stories and with the highest story not more than 30 ft (9.1 m) above the lowest level of firefighter access, less expensive residential class NFPA 13R sprinkler systems (page 262) are permitted as an alternative to commercial grade NFPA 13 systems. For such buildings, read the table on these two facing pages from the columns labeled *Res Spr*.

Special Height Exceptions

R-2 Occupancy buildings of 1-Hour Ordinary Construction may be up to six stories and 95 ft (29.0 m) in height, provided that the floor assembly separating basement areas from the floor at grade has a fire-resistance rating of at least 3 hours and the building contains continuous vertical 2-hour-rated fire walls that subdivide all floors into areas not exceeding 3000 sq ft (279 m^2).

R-2 Occupancy buildings of 1-Hour Noncombustible Construction may be up to nine stories and 100 ft (30.4 m) in height, provided that the floor assembly separating basement areas from the floor at grade level has a fire-resistance rating of at least 1½ hours, exits are separated from the rest of the building by 2-hour-rated fire walls, and the building is separated from other buildings and lot lines by a distance of at least 50 ft (15.2 m).

Where an R-2 Occupancy is constructed over a single-story at-grade S-2 Occupancy parking garage, the parking garage level

OCCUPANCY R-2: RESIDENTIAL, MULTIFAMILY

		Noncombustible							
CONSTRUCTION TYPE		**3-Hour (page 386)**		**2-Hour (page 386)**		**1-Hour (page 387)**		**Unprotected (page 387)**	
IBC NOMENCLATURE		**Type I-A**		**Type I-B**		**Type II-A**		**Type II-B**	
		Spr	**Res Spr**	**Spr**	**Res Spr**	**Spr**	**Res Spr**	**Spr**	**Res Spr**
MAXIMUM HEIGHT IN FEET		UH	30′[a]	180′	30′[a]	85′	30′[a]	75′	30′[a]
HEIGHT IN STORIES ABOVE GRADE AND MAXIMUM AREA IN SQ FT FOR ALL FLOORS	UH	UA							
	12			UA					
	11								
	10								
	9								
	8								
	7								
	6								
	5					216,000		144,000	
	4		UA		UA	216,000	72,000	144,000	48,000
	3					216,000	72,000	144,000	48,000
	2					144,000	48,000	96,000	32,000
	1					96,000	24,000	64,000	16,000
MAXIMUM AREA IN SQ FT FOR ANY SINGLE FLOOR OF A MULTISTORY BUILDING		UA	UA	UA	UA	72,000	24,000	48,000	16,000

Each number in the table represents the maximum total area in square feet for all floors for a building of the indicated story height.

[a]Height is measured from the lowest level of firefighter access to highest occupied floor.

Key to Abbreviations

UA	Unlimited area	Spr	With NFPA 13 sprinkler system throughout the building
UH	Unlimited height	Res Spr	Residential class NFPA 13R sprinkler system
NP	Not permitted		

is omitted when counting the number of stories. The floor above the parking garage must have a 1- or 2-hour fire-resistance rating.

Excess Frontage

See page 434 for an explanation of applying excess frontage to allowable area increases in Residential Occupancy buildings.

Measurements

Height is measured from the average finished ground level adjoining the building to the average level of the highest roof. Floor area is measured within exterior walls or exterior walls and fire walls, exclusive of courtyards. Basements are not included in area calculations, provided that their area does not exceed the area permitted for a one-story building.

$1 ft = 304.8 mm, 1 sq ft = 0.0929 m^2$

Further Information

Occupancy classifications: page 6.
Mixed-use buildings: page 374.
Which code to consult: pages 5–6.

Mixed Combustible/Noncombustible												Combustible				
Ordinary				Mass Timber & Heavy Timber								Wood Light Frame				
1-Hour (page 387)		Unprotected (page 387)		Mass Timber (page 388)						Heavy Timber (page 388)		1-Hour (page 391)		Unprotected (page 391)		
Type III-A		Type III-B		Type IV-A		Type IV-B		Type IV-C		Type IV-HT		Type V-A		Type V-B		
Spr	Res Spr	Spr	Res Spr	Spr	Res Spr	Spr	Res Spr	Spr	Res Spr	Spr	Res Spr	Spr	Res Spr	Spr	Res Spr	
85′	30′[a]	75′	30′[a]	270′	30′[a]	180′	30′[a]	85′	30′[a]	85′	30′[a]	70′	30′[a]	60′	30′[a]	
				18 stories max												UH
				553,500		369,000										12
				553,500		369,000										11
				553,500		369,000										10
				553,500		369,000										9
				553,500		369,000		230,625								8
				553,500		369,000		230,625								7
				553,500		369,000		230,625								6
216,000		144,000		553,500		369,000		230,625		184,500						5
216,000	72,000	144,000	48,000	553,500	184,500	369,000	123,000	230,625	76,875	184,500	61,500	108,000	36,000			4
216,000	72,000	144,000	48,000	553,500	184,500	369,000	123,000	230,625	76,875	184,500	61,500	108,000	36,000	63,000	21,000	3
144,000	48,000	96,000	32,000	369,000	123,000	246,000	82,000	153,750	51,250	123,000	41,000	72,000	24,000	42,000	14,000	2
96,000	24,000	64,000	16,000	246,000	61,500	164,000	41,000	102,500	25,625	82,000	20,500	48,000	12,000	28,000	7,000	1
72,000	24,000	48,000	16,000	184,500	61,500	123,000	41,000	76,875	25,625	61,500	20,500	36,000	12,000	21,000	7,000	

This table was compiled from information contained in the International Building Code 2021. It does not represent an official interpretation by the organization that issues this code.

OCCUPANCY R-3: RESIDENTIAL, MISCELLANEOUS

International Residential Code

Detached residential one- and two-family dwellings and townhouses are governed by the *International Residential Code*, a separate model code. For buildings of this type, use the following preliminary guidelines:

- Residences must be sprinklered with a light-duty NFPA 13D (page 262) or equivalent system. However, adoption of this requirement varies among jurisdictions and you should check your local code before assuming this requirement applies to your project.
- Building height is limited to three stories. Area is unlimited.
- Buildings may be of any Construction Type.
- Each dwelling unit must have its own separate means of egress.
- Townhouses must have yards or public ways on at least two sides. Common walls between townhouses must be 1-hour rated if the buildings are sprinklered, or otherwise 2-hour rated.
- Dwelling units in two-family buildings must be separated by 1-hour-rated wall and floor/ceiling assemblies.
- Every habitable basement and sleeping room must have at least one emergency window or door to the exterior. See page 297.

International Building Code

The International Building Code R-3 Occupancy classification governs one- and two-family buildings that exceed the limits of the International Residential Code listed above. It also includes congregate living facilities with 16 or fewer permanent occupants or 10 or fewer transient residents, and adult or child day care facilities for 5 or fewer persons. For such buildings, use the table on these two facing pages to determine building height and area limitations.

OCCUPANCY R-3: RESIDENTIAL, MISCELLANEOUS

		Noncombustible							
CONSTRUCTION TYPE		3-Hour (page 386)		2-Hour (page 386)		1-Hour (page 387)		Unprotected (page 387)	
IBC NOMENCLATURE		Type I-A		Type I-B		Type II-A		Type II-B	
		Spr	Res Spr	Spr	Res Spr	Spr	Res Spr	Spr	Res Spr
MAXIMUM HEIGHT IN FEET		UH	30′[a]	180′	30′[a]	85′	30′[a]	75′	30′[a]
HEIGHT IN STORIES ABOVE GRADE AND MAXIMUM AREA IN SQ FT FOR ALL FLOORS	UH	UA							
	12			UA					
	11								
	10								
	9								
	8								
	7								
	6								
	5					UA		UA	
	4		UA		UA		UA		UA
	3								
	2								
	1								
MAXIMUM AREA IN SQ FT FOR ANY SINGLE FLOOR OF A MULTISTORY BUILDING		UA	UA	UA	UA	UA	UA	UA	UA

Each number in the table represents the maximum total area in square feet for all floors for a building of the indicated story height.

[a]Height is measured from the lowest level of firefighter access to highest occupied floor.

Key to Abbreviations

UA	Unlimited area	Spr	With NFPA 13 sprinkler system throughout the building
UH	Unlimited height	Res Spr	Residential class NFPA 13R sprinkler system
NP	Not permitted		

Sprinklers

A sprinkler system is required throughout *entire buildings* containing, in whole or in part, an R-3 Occupancy.

In buildings not more than four stories and with the highest story not more than 30 ft (9.1 m) above the lowest level of firefighter access, less expensive residential class NFPA 13R sprinkler systems (page 262) are permitted as an alternative to commercial grade NFPA 13 systems. For such buildings, read the table on these two facing pages from the columns labeled *Res Spr*.

Dwelling Unit Separations

Individual dwelling units in a two-family building must be separated by 1-hour fire-resistance-rated wall and floor/ceiling assemblies. Common walls separating adjoining townhouses must be 2-hour rated.

Measurements

Height is measured from the average finished ground level adjoining the building to the average level of the highest roof. Floor area is measured within exterior walls or exterior walls and fire walls, exclusive of courtyards. Basements are not included in area calculations, provided that their area does not exceed the area permitted for a one-story building.

1 ft = 304.8 mm, 1 sq ft = 0.0929 m^2

Further Information

Occupancy classifications: page 6.
Mixed-use buildings: page 374.
Which code to consult: pages 5–6.

Mixed Combustible/Noncombustible												Combustible			
Ordinary				Mass Timber & Heavy Timber								Wood Light Frame			
1-Hour (page 387)		Unprotected (page 387)		Mass Timber (page 388)						Heavy Timber (page 388)		1-Hour (page 391)		Unprotected (page 391)	
Type III-A		Type III-B		Type IV-A		Type IV-B		Type IV-C		Type IV-HT		Type V-A		Type V-B	
Spr	Res Spr	Spr	Res Spr	Spr	Res Spr	Spr	Res Spr	Spr	Res Spr	Spr	Res Spr	Spr	Res Spr	Spr	Res Spr
85′	30′[a]	75′	30′[a]	270′	30′[a]	180′	30′[a]	85′	30′[a]	85′	30′[a]	70′	30′[a]	60′	30′[a]
UA	UA	UA	UA	18 stories max UA	UA	UA	UA	UA	UA	UA	UA	UA	UA	UA	UA
UA	UA	UA	UA	UA	UA	UA	UA	UA	UA	UA	UA	UA	UA	UA	UA

UH 12 11 10 9 8 7 6 5 4 3 2 1

This table was compiled from information contained in the International Building Code 2021. It does not represent an official interpretation by the organization that issues this code.

OCCUPANCY R-4: RESIDENTIAL, RESIDENTIAL CARE

International Residential Code

Structures housing activities classified as R-4 Occupancy may be constructed to the requirements of the International Residential Code if they fall within the requirements of this other code. For more information on the International Residential Code, see page 438.

Sprinklers

A sprinkler system is required throughout *entire buildings* containing, in whole or in part, an R-4 Occupancy.

In buildings not more than four stories and with the highest story not more than 30 ft (9.1 m) above the lowest level of firefighter access, less expensive residential class NFPA 13R sprinkler systems (page 262) are permitted as an alternative to commercial grade NFPA 13 systems. For such buildings, read the table on these two facing pages from the columns labeled *Res Spr*.

Excess Frontage

See page 434 for an explanation of applying excess frontage to allowable area increases in Residential Occupancy buildings.

Measurements

Height is measured from the average finished ground level adjoining the building to the average level

OCCUPANCY R-4: RESIDENTIAL, ASSISTED LIVING

		Noncombustible							
CONSTRUCTION TYPE		**3-Hour (page 386)**		**2-Hour (page 386)**		**1-Hour (page 387)**		**Unprotected (page 387)**	
IBC NOMENCLATURE		**Type I-A**		**Type I-B**		**Type II-A**		**Type II-B**	
		Spr	**Res Spr**	**Spr**	**Res Spr**	**Spr**	**Res Spr**	**Spr**	**Res Spr**
MAXIMUM HEIGHT IN FEET		UH	30′[a]	180′	30′[a]	85′	30′[a]	75′	30′[a]
HEIGHT IN STORIES ABOVE GRADE AND MAXIMUM AREA IN SQ FT FOR ALL FLOORS	UH	UA							
	12			UA					
	11								
	10								
	9								
	8								
	7								
	6								
	5					216,000		144,000	
	4		UA		UA	216,000	72,000	144,000	48,000
	3					216,000	72,000	144,000	48,000
	2					144,000	48,000	96,000	32,000
	1					96,000	24,000	64,000	16,000
MAXIMUM AREA IN SQ FT FOR ANY SINGLE FLOOR OF A MULTISTORY BUILDING		UA	UA	UA	UA	72,000	24,000	48,000	16,000

Each number in the table represents the maximum total area in square feet for all floors for a building of the indicated story height.

[a]Height is measured from the lowest level of firefighter access to highest occupied floor.

Key to Abbreviations

UA	Unlimited area	Spr	With NFPA 13 sprinkler system throughout the building
UH	Unlimited height	Res Spr	Residential class NFPA 13R sprinkler system
NP	Not permitted		

of the highest roof. Floor area is measured within exterior walls or exterior walls and fire walls, exclusive of courtyards. Basements are not included in area calculations, provided that their area does not exceed the area permitted for a one-story building.

$$1\,\text{ft} = 304.8\,\text{mm}, 1\,\text{sq ft} = 0.0929\,\text{m}^2$$

Further Information

Occupancy classifications: page 6.
Mixed-use buildings: page 374.
Which code to consult: pages 5–6.

Mixed Combustible/Noncombustible												Combustible				
Ordinary				Mass Timber & Heavy Timber								Wood Light Frame				
1-Hour (page 387)		Unprotected (page 387)		Mass Timber (page 388)						Heavy Timber (page 388)		1-Hour (page 391)		Unprotected (page 391)		
Type III-A		Type III-B		Type IV-A		Type IV-B		Type IV-C		Type IV-HT		Type V-A		Type V-B		
Spr	Res Spr	Spr	Res Spr	Spr	Res Spr	Spr	Res Spr	Spr	Res Spr	Spr	Res Spr	Spr	Res Spr	Spr	Res Spr	
85′	30′[a]	75′	30′[a]	270′	30′[a]	180′	30′[a]	85′	30′[a]	85′	30′[a]	70′	30′[a]	60′	30′[a]	
				18 stories max												UH
				553,500		369,000										12
				553,500		369,000										11
				553,500		369,000										10
				553,500		369,000										9
				553,500		369,000										8
				553,500		369,000										7
				553,500		369,000										6
216,000		144,000		553,500		369,000		230,625		184,500						5
216,000	72,000	144,000	48,000	553,500	184,500	369,000	123,000	230,625	76,875	184,500	61,500	108,000	36,000			4
216,000	72,000	144,000	48,000	553,500	184,500	369,000	123,000	230,625	76,875	184,500	61,500	108,000	36,000	63,000	21,000	3
144,000	48,000	96,000	32,000	369,000	123,000	246,000	82,000	153,750	51,250	123,000	41,000	72,000	24,000	42,000	14,000	2
96,000	24,000	64,000	16,000	246,000	61,500	164,000	41,000	102,500	25,625	82,000	20,500	48,000	12,000	28,000	7,000	1
72,000	24,000	48,000	16,000	184,500	61,500	123,000	41,000	76,875	25,625	61,500	20,500	36,000	12,000	21,000	7,000	

This table was compiled from information contained in the International Building Code 2021. It does not represent an official interpretation by the organization that issues this code.

OCCUPANCY S-1: STORAGE, MODERATE-HAZARD

Sprinklers

In addition to the requirements indicated in the table on these two facing pages, a sprinkler system is required throughout *entire buildings* meeting any of the following conditions:

- Containing an S-1 Occupancy fire area exceeding 12,000 sq ft (1115 m^2)
- Containing an S-1 fire area located four or more stories above grade
- Containing multiple S-1 fire areas, including mezzanines, that in total exceed 24,000 sq ft (2230 m^2) in area
- Containing an S-1 fire area exceeding 5000 sq ft (464 m^2) used for the storage of commercial motor vehicles
- Used for the storage of vehicular tires exceeding 20,000 cu ft (566 m^3) in volume
- Containing vehicle repair garages and exceeding certain size and height limitations. See the code for details.

A sprinkler system is required for all S-1 Occupancy *fire areas* meeting the following conditions:

- Fire areas exceeding exceed 2500 sq ft (232 m^2) used for the storage of upholstered furniture or mattresses
- Used for the bulk storage of distilled spirits or wine

A sprinkler system is also required throughout buildings containing S-1 Occupancy vehicle repair garages exceeding certain limits. For additional sprinkler requirements, see page 380.

Unlimited Area Buildings

Fully sprinklered one- or two-story S-1 Occupancy buildings may be of unlimited area when the building is surrounded on all sides by streets or open space not less than 40 to 60 ft (12.2 to 18.3 m) in width.

Excess Frontage

If more than 25% of a building perimeter fronts a street or open space at least 20 ft (6.1 m) wide, the area in the table on these two pages may be increased. For example, to determine the added area for a

OCCUPANCY S-1: STORAGE, MODERATE-HAZARD

		Noncombustible							
CONSTRUCTION TYPE		**3-Hour (page 386)**		**2-Hour (page 386)**		**1-Hour (page 387)**		**Unprotected (page 387)**	
IBC NOMENCLATURE		**Type I-A**		**Type I-B**		**Type II-A**		**Type II-B**	
		Spr	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**
MAXIMUM HEIGHT IN FEET		UH	75′[a]	180′	75′[a]	85′	65′	75′	55′
HEIGHT IN STORIES ABOVE GRADE AND MAXIMUM AREA IN SQ FT FOR ALL FLOORS	UH	UA	UA						
	12			432,000					
	11			432,000	144,000				
	10			432,000	144,000				
	9			432,000	144,000				
	8			432,000	144,000				
	7			432,000	144,000				
	6			432,000	144,000				
	5			432,000	144,000	234,000			
	4			432,000	144,000	234,000	78,000	157,500	
	3			432,000	144,000	234,000	78,000	157,500	
	2			288,000	96,000	156,000	52,000	105,000	35,000
	1			192,000	48,000	104,000	26,000	70,000	17,500
MAXIMUM AREA IN SQ FT FOR ANY SINGLE FLOOR OF A MULTISTORY BUILDING		UA	UA	144,000	48,000	78,000	26,000	52,500	17,500

Each number in the table represents the maximum total area in square feet for all floors for a building of the indicated story height.

[a]Height is measured from the lowest level of firefighter access to highest occupied floor.

Key to Abbreviations

UA	Unlimited area	Spr	With sprinkler system throughout the building
UH	Unlimited height	Unspr	Without a fully sprinklered building
NP	Not permitted		

building with 60% of its perimeter fronting a space 24 ft wide:

1. Determine the excess frontage: 60% – 25% = 35% excess frontage

2. From the following table, read the area increase for each percent of excess frontage: 0.80

Width of Frontage	Area Increase for Each Percent of Excess Frontage[a]
20′ (6.1 m)	0.67
22′ (6.7 m)	0.73
24′ (7.3 m)	0.80
26′ (7.9 m)	0.87
28′ (8.5 m)	0.93
30′ (9.1 m) or wider	1.00

[a]Intermediate values may be interpolated.

3. Calculate the area increase: 0.80 × 35% = 28%

4. In Storage Occupancy buildings, the added area for excess frontage is determined using unsprinklered area allowances. To find the added area for one floor, read the lowest figure in the unsprinklered column for your construction type and multiply this figure by the area increase calculated in the previous step. Continuing the example, assuming an S-1 Occupancy, Type V-A building, sprinklered or unsprinklered with the excess frontage described above, the added area per floor would be 28% × 14,000 sq ft = 3920 sq ft. For a two-story building, the added area would be twice this amount, or 7840 sq ft, and for a building three or more stories in height, 3 times this amount, or 11,760 sq ft.

Measurements

Height is measured from the average finished ground level adjoining the building to the average level of the highest roof. Floor area is measured within exterior walls or exterior walls and fire walls, exclusive of courtyards. Basements are not included in area calculations, provided that their area does not exceed the area permitted for a one-story building.

1 ft = 304.8 mm, 1 sq ft = 0.0929 m²

Mixed Combustible/Noncombustible												Combustible				
Ordinary				Mass Timber & Heavy Timber								Wood Light Frame				
1-Hour (page 387)		Unprotected (page 387)		Mass Timber (page 388)						Heavy Timber (page 388)		1-Hour (page 391)		Unprotected (page 391)		
Type III-A		Type III-B		Type IV-A		Type IV-B		Type IV-C		Type IV-HT		Type V-A		Type V-B		
Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	
85′	65′	75′	55′	270′	65′	180′	65′	85′	65′	85′	65′	70′	50′	60′	40′	
																UH
																12
																11
				432,000												10
				432,000												9
				432,000												8
				432,000		432,000										7
				432,000		432,000										6
				432,000		432,000		432,000		229,500						5
234,000		157,500		432,000	229,500	432,000	153,000	432,000	95,625	229,500		126,000				4
234,000	78,000	157,500		432,000	229,500	432,000	153,000	432,000	95,625	229,500	76,500	126,000	42,000			3
156,000	52,000	105,000	35,000	288,000	153,000	288,000	102,000	288,000	63,750	153,000	51,000	84,000	28,000	54,000		2
104,000	26,000	70,000	17,500	306,000	76,500	204,000	51,000	127,500	31,875	102,000	25,500	56,000	14,000	36,000	9,000	1
78,000	26,000	52,500	17,500	229,500	76,500	153,000	51,000	95,625	31,875	76,500	25,500	42,000	14,000	27,000	9,000	

This table was compiled from information contained in the International Building Code 2021. It does not represent an official interpretation by the organization that issues this code.

OCCUPANCY S-2: STORAGE, LOW-HAZARD

Sprinklers

In addition to the requirements indicated in the table on these two facing pages, *entire buildings* containing, in whole or in part, parking garages meeting any of the following requirements must be sprinklered throughout:

- The fire area of an enclosed garage is greater than 12,000 sq ft (1115 m^2).
- An enclosed garage is located below any Occupancy other than R-3.
- The fire area of an open garage is greater than 48,000 sq ft (4460 m^2).
- The fire area of an open or enclosed garage used for the storage of commercial vehicles is greater than 5000 sq ft (464 m^2).
- An enclosed garage houses an automated, mechanical-access parking system.

For additional sprinkler requirements, see page 380.

Unlimited Height and Area Buildings

S-2 Occupancy buildings, either one-story unsprinklered or two-story fully sprinklered, may be of unlimited area when the building is surrounded on all sides by streets or open space not less than 40 to 60 ft (12.2 to 18.3 m) in width.

Vehicle Parking Garages

For enclosed, mechanically ventilated parking garages or for naturally ventilated open parking garages combined with other Occupancies, use the height and area table on these two facing pages. For buildings containing solely open parking, see pages 44–447. For private garages and carports, see Occupancy U: Utility, on pages 448–449. For specially permitted mixed-use garage configurations, see page 376.

Open parking garages may be of only Noncombustible Type I

OCCUPANCY S-2: STORAGE, LOW-HAZARD

	Noncombustible							
CONSTRUCTION TYPE	**3-Hour (page 386)**		**2-Hour (page 386)**		**1-Hour (page 387)**		**Unprotected (page 387)**	
IBC NOMENCLATURE	**Type I-A**		**Type I-B**		**Type II-A**		**Type II-B**	
	Spr	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**
MAXIMUM HEIGHT IN FEET	UH	75′[a]	180′	75′[a]	85′	65′	75′	55′
HEIGHT IN STORIES ABOVE GRADE AND MAXIMUM AREA IN SQ FT FOR ALL FLOORS UH	UA	UA						
12			711,000					
11			711,000	237,000				
10			711,000	237,000				
9			711,000	237,000				
8			711,000	237,000				
7			711,000	237,000				
6			711,000	237,000	351,000			
5			711,000	237,000	351,000	117,000		
4			711,000	237,000	351,000	117,000	234,000	
3			711,000	237,000	351,000	117,000	234,000	78,000
2			474,000	158,000	234,000	78,000	156,000	52,000
1			316,000	79,000	156,000	39,000	104,000	26,000
MAXIMUM AREA IN SQ FT FOR ANY SINGLE FLOOR OF A MULTISTORY BUILDING	UA	UA	237,000	79,000	117,000	39,000	78,000	26,000

Each number in the table represents the maximum total area in square feet for all floors for a building of the indicated story height.

[a]Height is measured from the lowest level of firefighter access to highest occupied floor.

Key to Abbreviations

UA	Unlimited area	Spr	With sprinkler system throughout the building
UH	Unlimited height	Unspr	Without a fully sprinklered building
NP	Not permitted		

or Mass Timber & Heavy Timber Type IV Construction. They may not include vehicle repair work, the dispensing of fuel, or the parking of commercial buses or trucks. For wall opening and building separation distance requirements for open parking garages, see page 351.

The minimum clear height within parking garage tiers is 7 ft (2.1 m). Parking is permitted on garage roofs. For more information on the design of parking facilities, see Designing for Parking, beginning on page 337.

Excess Frontage

See page 442 for an explanation of applying excess frontage to allowable area increases in Storage Occupancy buildings.

Measurements

Height is measured from the average finished ground level adjoining the building to the average level of the highest roof. Floor area is measured within exterior walls or exterior walls and fire walls, exclusive of courtyards. Basements are not included in area calculations, provided that their area does not exceed the area permitted for a one-story building.

1 ft = 304.8 mm, 1 sq ft = 0.0929 m^2

Further Information

Occupancy classifications: page 6.
Mixed-use buildings: page 374.
Which code to consult: pages 5–6.

Mixed Combustible/Noncombustible												Combustible				
Ordinary				Mass Timber & Heavy Timber								Wood Light Frame				
1-Hour (page 387)		Unprotected (page 387)		Mass Timber (page 388)						Heavy Timber (page 388)		1-Hour (page 391)		Unprotected (page 391)		
Type III-A		Type III-B		Type IV-A		Type IV-B		Type IV-C		Type IV-HT		Type V-A		Type V-B		
Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	
85′	65′	75′	55′	270′	65′	180′	65′	85′	65′	85′	65′	70′	50′	60′	40′	
																UH
				1,039,500												12
				1,039,500												11
				1,039,500												10
				1,039,500												9
				1,039,500		693,000										8
				1,039,500		693,000										7
				1,039,500		693,000				346,500						6
351,000				1,039,500		693,000		433,125		346,500	115,500	189,000				5
351,000	117,000	234,000		1,039,500	346,500	693,000	231,000	433,125	144,375	346,500	115,500	189,000	63,000			4
351,000	117,000	234,000	78,000	1,039,500	346,500	693,000	231,000	433,125	144,375	346,500	115,500	189,000	63,000	121,500		3
234,000	78,000	156,000	52,000	693,000	231,000	462,000	154,000	288,750	96,250	231,000	77,000	126,000	42,000	81,000	27,000	2
156,000	39,000	104,000	26,000	462,000	115,500	308,000	77,000	192,500	48,125	154,000	38,500	84,000	21,000	54,000	13,500	1
117,000	39,000	78,000	26,000	346,500	115,500	231,000	77,000	144,375	48,125	115,500	38,500	63,000	21,000	40,500	13,500	

This table was compiled from information contained in the International Building Code 2021. It does not represent an official interpretation by the organization that issues this code.

OCCUPANCY S-2: OPEN PARKING GARAGES

Use the information on these two facing pages for structures containing only single-use, open parking garages. To qualify, two or more sides of the structure must be substantially open to the passage of air and the garage must be used for the parking or storage of private motor vehicles only, excluding commercial motor vehicles. For all other commercial parking structures, see pages 444–445. For private garages and carports, see pages 448–449.

Mixed occupancies are not permitted, except that up to 1000 sq ft (93 m^2) of office space, toilet facilities, and waiting area may be included on the ground level. The minimum vertical clear height within parking garage tiers is 7 ft (2.1 m). Rooftops may be used as parking.

For wall opening and building separation distance requirements for open parking garages, see page 351. For general information on the design of parking facilities, see Designing for Parking, beginning on page 337.

Height and Area Increases

For garages open on three sides, the heights and areas tabulated on these two facing pages may be increased by one floor and 25%, respectively. For garages open on four sides, these values may be increased by one floor and 50%. To apply these increases, wall openings must equal at least 50% of the wall area and be equally distributed along the wall's length.

For garages open on four sides, constructed of Type II, 1-Hour or Unprotected Noncombustible Construction, and not more than 75 ft (22.9 m) in height, floor area is unlimited. Wall opening area must meet the requirements of the previous paragraph, and no point on any floor may be more than 200 ft (61 m) from such openings.

OCCUPANCY S-2: OPEN PARKING GARAGES

		Noncombustible							
CONSTRUCTION TYPE		3-Hour (page 386)		2-Hour (page 386)		1-Hour (page 387)		Unprotected (page 387)	
IBC NOMENCLATURE		Type I-A		Type I-B		Type II-A		Type II-B	
		Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr
MAXIMUM HEIGHT IN FEET		UH	UH	UH	UH	UH	UH	UH	UH
HEIGHT IN STORIES ABOVE GRADE AND MAXIMUM AREA IN SQ FT FOR ALL FLOORS	UH	UA	UA						
	12			UA	UA				
	11								
	10					500,000	500,000		
	9					450,000	450,000		
	8					400,000	400,000	400,000	400,000
	7					350,000	350,000	350,000	350,000
	6					300,000	300,000	300,000	300,000
	5					250,000	250,000	250,000	250,000
	4					200,000	200,000	200,000	200,000
	3					150,000	150,000	150,000	150,000
	2					100,000	100,000	100,000	100,000
	1					50,000	50,000	50,000	50,000
MAXIMUM AREA IN SQ FT FOR ANY SINGLE FLOOR OF A MULTISTORY BUILDING		UA	UA	UA	UA	50,000	50,000	50,000	50,000

Each number in the table represents the maximum total area in square feet for all floors for a building of the indicated story height.

Key to Abbreviations

UA	Unlimited area	Spr	With sprinkler system throughout the building
UH	Unlimited height	Unspr	Without a fully sprinklered building
NP	Not permitted		

For garages with openings on at least three sides and with less than the maximum permitted number of stories, the combined area of all floors may be increased to as much as that permitted for the maximum height structure. For example, for a Type I-B, 2-hour Noncombustible open parking garage, five floors in height, the tabulated maximum area for all floors is 250,000 sq ft (50,000 sq ft per floor). With this area increase, the area of all floors may be as much as 500,000 sq ft (100,000 sq ft per floor). To apply this increase, at least three sides of the garage must have continuous wall openings and no point on any floor may be more than 200 ft (61 m) from such an opening. Wall openings must be at least 30 in. (760 mm) in height, extend for at least 80% of the length of the wall, and must face streets at least 30 ft (9.1 m) in width or yards of equal width accessible to firefighting equipment. Standpipes for fire hose connections must also serve each floor.

The allowable number of floors may also be increased by as much as 50% for open parking garages that are fully sprinklered, have limited public access, and use lifts or other mechanical devices to move vehicles to and from the street level.

Measurements

Height is measured from the average finished ground level adjoining the building to the average level of the highest roof. Floor area is measured within exterior walls or exterior walls and fire walls, exclusive of courtyards.

$$1\,\text{ft} = 304.8\,\text{mm}, 1\,\text{sq ft} = 0.0929\,\text{m}^2$$

Further Information

Occupancy classifications: page 6.
Mixed-use buildings: page 374.
Which code to consult: pages 5–6.

Mixed Combustible/Noncombustible												**Combustible**				
Ordinary				**Mass Timber & Heavy Timber**								**Wood Light Frame**				
1-Hour (page 387)		**Unprotected (page 387)**		**Mass Timber (page 388)**						**Heavy Timber (page 388)**		**1-Hour (page 391)**		**Unprotected (page 391)**		
Type III-A		**Type III-B**		**Type IV-A**		**Type IV-B**		**Type IV-C**		**Type IV-HT**		**Type V-A**		**Type V-B**		
Spr	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**	
				UH	UH	UH	UH	UH	UH	UH	UH					
																UH
																12
																11
																10
																9
																8
																7
																6
																5
				200,000	200,000	200,000	200,000	200,000	200,000	200,000	200,000					4
				150,000	150,000	150,000	150,000	150,000	150,000	150,000	150,000					3
				100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000					2
NP	NP	NP	NP	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	NP	NP	NP	NP	1
				50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000					

This table was compiled from information contained in the International Building Code 2021. It does not represent an official interpretation by the organization that issues this code.

OCCUPANCY U: UTILITY

Private Garages and Carports

Private garages attached to residences must be separated from adjacent living areas by construction including at least ½-in. (12.5-mm) gypsum wallboard or, where living space is located above the garage, with at least ⅝-in. (16-mm) Type X fire-resistant gypsum wallboard. Doors separating living space from private garages must be self-closing, self-latching, not less than 1⅜ in. (35 mm) thick, and made of solid wood or hollow metal, or they may be of other types with at least a 20-minute fire rating. Windows, doors, and other openings between garages and sleeping areas are not permitted. Garage floor surfaces must be noncombustible. No separation is required between carports open on at least two sides and R-3 Occupancies, except that where living space is located above the carport, the floor/ceiling construction must be protected with at least ⅝-in. (16-mm) Type X gypsum wallboard. Carport floor surfaces must be noncombustible or asphalt.

Occupancy U private garages and carports are limited to 1000 sq ft (93 m^2) in area. Private garages within mixed-use buildings are considered accessory to the main use, and height and area limitations for building are determined according to the requirements of the major Occupancy. When regulated by the International Residential Code, there are no area limitations on private garages or carports (see page 438 for the building types that apply).

Private garages exceeding Occupancy U area limitations must be classified as Occupancy S-2, or 1-hour rated walls and floor/ceiling assemblies may be used to divide the garage area into multiple separated garages complying with U Occupancy private garage limits.

Excess Frontage

If more than 25% of a building perimeter fronts a street or open space at least 20 ft (6.1 m) wide, the area in the table on these two pages may be increased. For example,

OCCUPANCY U: UTILITY AND MISCELLANEOUS

		Noncombustible							
CONSTRUCTION TYPE		**3-Hour (page 386)**		**2-Hour (page 386)**		**1-Hour (page 387)**		**Unprotected (page 387)**	
IBC NOMENCLATURE		**Type I-A**		**Type I-B**		**Type II-A**		**Type II-B**	
		Spr	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**
MAXIMUM HEIGHT IN FEET		UH	75′[a]	180′	75′[a]	85′	65′	75′	55′
HEIGHT IN STORIES ABOVE GRADE AND MAXIMUM AREA IN SQ FT FOR ALL FLOORS	UH	UA	UA						
	12								
	11								
	10								
	9								
	8								
	7								
	6			319,500					
	5			319,500	106,500	171,000			
	4			319,500	106,500	171,000	57,000		
	3			319,500	106,500	171,000	57,000	76,500	
	2			213,000	71,000	114,000	38,000	51,000	17,000
	1			142,000	35,500	76,000	19,000	34,000	8,500
MAXIMUM AREA IN SQ FT FOR ANY SINGLE FLOOR OF A MULTISTORY BUILDING		UA	UA	106,500	35,500	57,000	19,000	25,500	8,500

Each number in the table represents the maximum total area in square feet for all floors for a building of the indicated story height.

[a]Height is measured from the lowest level of firefighter access to highest occupied floor.

Key to Abbreviations

UA	Unlimited area	Spr	With sprinkler system throughout the building
UH	Unlimited height	Unspr	Without a fully sprinklered building
NP	Not permitted		

to determine the added area for a building with 60% of its perimeter fronting a space 24 ft wide:

1. Determine the excess frontage: 60% – 25% = 35% excess frontage

2. From the following table, read the area increase for each percent of excess frontage: 0.80

Width of Frontage	Area Increase for Each Percent of Excess Frontage[a]
20′ (6.1 m)	0.67
22′ (6.7 m)	0.73
24′ (7.3 m)	0.80
26′ (7.9 m)	0.87
28′ (8.5 m)	0.93
30′ (9.1 m) or wider	1.00

[a]Intermediate values may be interpolated.

3. Calculate the area increase: 0.80 × 35% = 28%

4. In Utility Occupancy buildings, the added area for excess frontage is determined using unsprinklered area allowances. To find the added area for one floor, read the lowest figure in the unsprinklered column for your construction type and multiply this figure by the area increase calculated in the previous step. Continuing the example, assuming a U Occupancy, Type III-A building, sprinklered or unsprinklered with the excess frontage described above, the added area per floor would be 28% × 14,000 sq ft = 3920 sq ft. For a two-story building, the added area would be twice this amount, or 7840 sq ft, and for a building three or more stories in height, 3 times this amount, or 11,760 sq ft.

Measurements

Height is measured from the average finished ground level adjoining the building to the average level of the highest roof. Floor area is measured within exterior walls or exterior walls and fire walls, exclusive of courtyards. Basements are not included in area calculations, provided that their area does not exceed the area permitted for a one-story building.

$1\,\text{ft} = 304.8\,\text{mm}, 1\,\text{sq ft} = 0.0929\,\text{m}^2$

Mixed Combustible/Noncombustible												Combustible				
Ordinary				Mass Timber & Heavy Timber								Wood Light Frame				
1-Hour (page 387)		Unprotected (page 387)		Mass Timber (page 388)						Heavy Timber (page 388)		1-Hour (page 391)		Unprotected (page 391)		
Type III-A		Type III-B		Type IV-A		Type IV-B		Type IV-C		Type IV-HT		Type V-A		Type V-B		
Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	
85′	65′	75′	55′	270′	65′	180′	65′	85′	65′	85′	65′	70′	50′	60′	40′	
																UH
																12
																11
																10
				486,000												9
				486,000												8
				486,000												7
				486,000		324,000										6
				486,000		324,000				162,000						5
126,000				486,000	162,000	324,000	108,000	202,500		162,000	54,000					4
126,000	42,000	76,500		486,000	162,000	324,000	108,000	202,500	67,500	162,000	54,000	81,000				3
84,000	28,000	51,000	17,000	324,000	108,000	216,000	72,000	135,000	45,000	108,000	36,000	54,000	18,000	33,000		2
56,000	14,000	34,000	8,500	216,000	54,000	144,000	36,000	90,000	22,500	72,000	18,000	36,000	9,000	22,000	5,500	1
42,000	14,000	25,500	8,500	162,000	54,000	108,000	36,000	67,500	22,500	54,000	18,000	27,000	9,000	16,500	5,500	

This table was compiled from information contained in the International Building Code 2021. It does not represent an official interpretation by the organization that issues this code.

HOW TO USE THE TABLES OF HEIGHT AND AREA LIMITATIONS FOR THE NATIONAL BUILDING CODE OF CANADA

1. Be sure you are consulting the tables for the proper building code. If you are not sure which code you are working under, see pages 6 and 13.

2. The Occupancy classification is given at the upper left-hand corner of the table. If you are not sure about the Occupancy into which your building falls, consult the indexes on pages 13–17.

3. Noncombustible Construction Types are tabulated on the left-hand page, Combustible Construction Types on the right-hand page.

4. Each pair of columns represents one Construction Type. For specific information on the different materials and modes of construction that conform to that Construction Type, follow the page reference given here.

5. For each Construction Type, the paired columns tabulate height and area information for both buildings fully sprinklered throughout (Spr) and buildings unsprinklered or only partially sprinklered (Unspr).

6. For the National Building Code of Canada, the tabulated areas represent maximum area per floor, for each floor of the building.

NATIONAL BUILDING CODE OF CANADA

OCCUPANCY D: BUSINESS AND PERSONAL SERVICES

Special Requirements

Buildings of Combustible, 1-Hour, sprinklered Construction meeting the requirements in the table on these two facing pages may include Miscellaneous Assembly A-2, Mercantile E, or Medium- or Low-Hazard Industrial F-2 or F-3 Occupancies on the first- and second-floor levels, or Low-Hazard Industrial F-3 Occupancy vehicular parking on the first- through third-floor levels.

For Business and Personal Services Occupancy buildings not more than three stories in height and 600 m² (6458 sq ft) in area per floor, see Small Buildings, page 373.

For additional sprinkler and basement requirements, see page 380.

Excess Frontage

For unsprinklered buildings, the tabulated areas may be increased by 25% if the building faces at least two streets and by 50% if it faces at least three. In unsprinklered 1- or 2-Hour Noncombustible Construction, a building two stories in height and facing two or three streets may be of unlimited area.

Measurements

Height is measured as the number of stories at grade or above, excluding the roof. Area is measured as the greatest horizontal projection of the building above grade within the outside surfaces of exterior walls or the centerline of fire walls.

Further Information

For information on Occupancy classifications, see page 13. For information on mixed-use buildings, see page 377. For information on which code to consult, see pages 5 and 13.

Unit Conversions

$1 m^2 = 10.76 sq ft$

OCCUPANCY D: BUSINESS AND PERSONAL SERVICES

CONSTRUCTION TYPE		Noncombustible							
		2-Hour (page 386)		1-Hour (page 387)		¾-Hour (page 387)		Unprotected (page 387)	
HEIGHT IN STORIES ABOVE GRADE AND MAXIMUM AREA PER FLOOR IN m²		Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr
	UH	UA							
	6	a.	2,400	7,200 b.	2,400				
	5		2,880	8,640	2,880				
	4		3,600	10,800	3,600				
	3		4,800	14,400	4,800	4,800	1,600	4,800	1,600
	2		7,200	UA	7,200	7,200	2,400	7,200	2,400
	1		UA	UA	UA	14,400	4,800	14,400	4,800

Each number in the table represents the maximum area per floor in square meters for each floor of a building of the indicated story height.

[a]See the accompanying text Special Requirements.

Key to Abbreviations

UA	Unlimited area	Spr	With sprinkler system throughout the building
UH	Unlimited height	Unspr	Without sprinkler system throughout the building
NP	Not permitted		

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NATIONAL BUILDING CODE OF CANADA

Combustible									
		Wood Light Frame							
Heavy Timber (page 390)		1-Hour (page 391)		¾-Hour (page 391)		Unprotected (page 391)			CONSTRUCTION TYPE
Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr		
								UH	HEIGHT IN STORIES ABOVE GRADE AND MAXIMUM AREA PER FLOOR IN m^2
		3,000						6	
		3,600						5	
		4,500						4	
4,800	1,600	6,000[a]	1,600	4,800	1,600			3	
7,200	2,400	9,000[a]	2,400	7,200	2,400			2	
14,400	4,800	18,000[a]	4,800	14,400	4,800	NP	NP	1	

This table was compiled from information contained in the National Building Code of Canada 2015. It does not represent an official interpretation by the organization that issues this code.

7. As an example of the use of this chart, a sprinklered building of Occupancy D, 1-Hour Noncombustible Construction, under the National Building Code of Canada, may be no more than (see shaded areas on chart):

a. Six stories tall

b. With no floor larger in area than 7200 m^2

8. As another example, if we wish to construct a three-story unsprinklered building of the same Occupancy classification with 3150 m^2 per floor, we must use 1-Hour Noncombustible Construction as a minimum. Looking to the right along the same row of the chart, we see that the addition of sprinklers would allow us to use ¾-Hour or Unprotected Noncombustible Construction, Heavy Timber Construction, or 1- or ¾-Hour Combustible Construction. By following the page references at the heads of these columns, we can determine exactly what each of these Construction Types is, and proceed to preliminary configuration and sizing of the structural system we select.

The reference tables appearing on the following pages are for preliminary design purposes only. They represent the authors' interpretation of certain major provisions of the National Building Code of Canada. No official interpretation has been sought from or granted by the National Research Council of Canada. For design development work and final preparation of building plans, you must consult the building codes and regulations in effect in your project's locale.

OCCUPANCY A-1: ASSEMBLY, THEATERS

Special Requirements

Where area per floor is indicated as 600 m^2:

- The total occupant load may not exceed 600.
- Up to 40% of the permitted area may be in a mezzanine or second story containing only nonpublic uses.

Where area per floor is indicated as UA with other than 2-hour Noncombustible Construction:

- The total occupant load may not exceed 300.
- The auditorium floor must be within 5 m (16 ft) of grade.

In mixed-occupancy buildings with an assembly seating occupancy greater than 200, the seating area must be separated from adjacent areas on the same floor by walls with fire-resistance ratings of ¾ to 1 hour.

For additional sprinkler and basement requirements, see page 380.

Measurements

Height is measured as the number of stories at grade or above, excluding the roof. Area is measured as the greatest horizontal projection of the building above grade within the outside surfaces of exterior walls or the centerline of fire walls.

Further Information

For information on Occupancy classifications, see page 13. For information on mixed-use buildings, see page 377. For information on which code to consult, see pages 5 and 13.

Unit Conversions

$$1\,m^2 = 10.76\,sq\,ft$$

OCCUPANCY A-1: ASSEMBLY, THEATERS

CONSTRUCTION TYPE		Noncombustible							
		2-Hour (page 386)		1-Hour (page 387)		¾-Hour (page 387)		Unprotected (page 387)	
		Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr
HEIGHT IN STORIES ABOVE GRADE AND MAXIMUM AREA PER FLOOR IN m^2	UH	UA							
	6								
	5								
	4								
	3								
	2								
	1		NP	600 or UA[a]	NP	600 or UA[a]	NP	NP	NP

Each number in the table represents the maximum area per floor in square meters for each floor of a building of the indicated story height.

[a]See the accompanying text Special Requirements.

Key to Abbreviations

UA	Unlimited area	Spr	With sprinkler system throughout the building
UH	Unlimited height	Unspr	Without a fully sprinklered building
NP	Not permitted		

Combustible									CONSTRUCTION TYPE
Heavy Timber (page 390)		Wood Light Frame							
		1-Hour (page 391)		¾-Hour (page 391)		Unprotected (page 391)			
Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr		HEIGHT IN STORIES ABOVE GRADE AND MAXIMUM AREA PER FLOOR IN m^2
								UH	
								6	
								5	
								4	
								3	
								2	
600 or UA[a]	NP	UA[a]	NP	UA[a]	NP	NP	NP	1	

This table was compiled from information contained in the National Building Code of Canada 2015. It does not represent an official interpretation by the organization that issues this code.

OCCUPANCY A-2: ASSEMBLY, MISCELLANEOUS

Special Requirements

For buildings of Unprotected Combustible Construction, sprinklered throughout:

- If single-story and without a basement, building area may be 2400 m² (25,833 sq ft).

For buildings of Unprotected Combustible Construction, unsprinklered:

- If without a basement, the building area shown in the accompanying table and modified for excess frontage may be doubled, provided that the building is divided by 1-hour fire separations into compartments each not exceeding the undoubled area.

See Special Requirements, page 466, for Miscellaneous Assembly Occupancies within buildings conforming to the height and area limits of Residential C Occupancies, or page 468, for Miscellaneous Assembly Occupancies within buildings conforming to the height and area limits of Business and Personal Services D Occupancies.

For additional sprinkler and basement requirements, see page 380.

Excess Frontage

For unsprinklered buildings, the tabulated areas may be increased by 25% if the building faces at least two streets and by 50% if it faces at least three.

Measurements

Height is measured as the number of stories at grade or above, excluding the roof. Area is measured as the greatest horizontal projection of the building above grade within the outside surfaces of exterior walls or the centerline of fire walls.

OCCUPANCY A-2: ASSEMBLY, MISCELLANEOUS

		Noncombustible							
CONSTRUCTION TYPE		**2-Hour (page 386)**		**1-Hour (page 387)**		**¾-Hour (page 387)**		**Unprotected (page 387)**	
		Spr	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**
HEIGHT IN STORIES ABOVE GRADE AND MAXIMUM AREA PER FLOOR IN m²	UH	UA							
	6			UA					
	5								
	4								
	3								
	2		800		800	2,400	800	2,400	800
	1		1,600		1,600	4,800	1,600	4,800	1,600

Each number in the table represents the maximum area per floor in square meters for each floor of a building of the indicated story height.

[a]See the accompanying text Special Requirements.

Key to Abbreviations

UA	Unlimited area	Spr	With sprinkler system throughout the building
UH	Unlimited height	Unspr	Without sprinkler system throughout the building
NP	Not permitted		

Further Information

For information on Occupancy classifications, see page 13. For information on mixed-use buildings, see page 377. For information on which code to consult, see pages 5 and 13.

Unit Conversions

$1\,m^2 = 10.76\,sq\,ft$

Combustible								CONSTRUCTION TYPE
		Wood Light Frame						
Heavy Timber (page 390)		1-Hour (page 391)		¾-Hour (page 391)		Unprotected (page 391)		
Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	HEIGHT IN STORIES ABOVE GRADE AND MAXIMUM AREA PER FLOOR IN m^2
								UH
								6
								5
								4
								3
2,400	800	2,400	800	2,400	800	600		2
4,800	1,600	4,800	1,600	4,800	1,600	1,200[a]	400[a]	1

This table was compiled from information contained in the National Building Code of Canada 2015. It does not represent an official interpretation by the organization that issues this code.

OCCUPANCY A-3: ASSEMBLY, ARENAS

Special Requirements

For unsprinklered buildings of 1- or 2-Hour Noncombustible Construction:

- Roofs and their supporting structure may be of Heavy Timber Construction.
- If used for trade shows or exhibitions and with floors greater than 1500 m² (16,146 sq ft) in area, the building must be sprinklered throughout.

All buildings used for trade shows or exhibitions and with floors greater than 1500 m² (16,146 sq ft) in area must be sprinklered throughout.

Long-span roofs over arenas, sports facilities, and other such spaces are not required to have a fire-resistance rating when not less than 6 m (20 ft) above the floor and supporting normal roof loads only.

For additional sprinkler and basement requirements, see page 380.

Excess Frontage

For unsprinklered buildings, the tabulated areas may be increased by 25% if the building faces at least two streets and by 50% if it faces at least three.

Measurements

Height is measured as the number of stories at grade or above, excluding the roof. Area is measured as the greatest horizontal projection of the building above grade within the outside surfaces of exterior walls or the centerline of fire walls.

Further Information

For information on Occupancy classifications, see page 13. For information on mixed-use buildings, see page 377. For information on which code to consult, see pages 5 and 13.

Unit Conversions

$$1\,m^2 = 10.76\,sq\,ft$$

OCCUPANCY A-3: ASSEMBLY, ARENAS

CONSTRUCTION TYPE	Noncombustible							
	2-Hour (page 386)		1-Hour (page 387)		¾-Hour (page 387)		Unprotected (page 387)	
	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr
HEIGHT IN STORIES ABOVE GRADE AND MAXIMUM AREA PER FLOOR IN m² UH	UA							
6								
5								
4								
3								
2		2,000[a]	6,000	2,000[a]				
1		4,000[a]	12,000	4,000[a]	7,200	2,400	7,200	2,400

Each number in the table represents the maximum area per floor in square meters for each floor of a building of the indicated story height.

[a]See the accompanying text Special Requirements.

Key to Abbreviations

UA	Unlimited area	Spr	With sprinkler system throughout the building
UH	Unlimited height	Unspr	Without sprinkler system throughout the building
NP	Not permitted		

Combustible									CONSTRUCTION TYPE
Heavy Timber (page 390)		Wood Light Frame							
		1-Hour (page 391)		¾-Hour (page 391)		Unprotected (page 391)			
Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr		HEIGHT IN STORIES ABOVE GRADE AND MAXIMUM AREA PER FLOOR IN m²
								UH	
								6	
								5	
								4	
								3	
								2	
7,200	2,400	7,200	2,400	7,200	2,400	7,200	1,000	1	

This table was compiled from information contained in the National Building Code of Canada 2015. It does not represent an official interpretation by the organization that issues this code.

OCCUPANCY A-4: ASSEMBLY, OPEN AIR

Special Requirements

Buildings of Combustible Construction must have an occupant load of less than 1500 and limiting distance (see page 381) of not less than 6 m (20 ft).

Long-span roofs over arenas, sports facilities, and other such spaces are not required to have a fire-resistance rating when not less than 6 m (20 ft) above the floor and supporting normal roof loads only.

Occupied areas below seating tiers must be sprinklered.

For additional sprinkler and basement requirements, see page 380.

Measurements

Height is measured as the number of stories at grade or above, excluding the roof. Area is measured as the greatest horizontal projection of the building above grade within the outside surfaces of exterior walls or the centerline of fire walls.

Further Information

For information on Occupancy classifications, see page 13. For information on mixed-use buildings, see page 377. For information on which code to consult, see pages 5 and 13.

Unit Conversions

$$1\,m^2 = 10.76\,sq\,ft$$

OCCUPANCY A-4: ASSEMBLY, OPEN-AIR

		Noncombustible							
CONSTRUCTION TYPE		**2-Hour (page 386)**		**1-Hour (page 387)**		**¾-Hour (page 387)**		**Unprotected (page 387)**	
		Spr	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**
HEIGHT IN STORIES ABOVE GRADE AND MAXIMUM AREA PER FLOOR IN m^2	UH	UA	UA	UA	UA	UA	UA	UA	UA
	6								
	5								
	4								
	3								
	2								
	1								

Each number in the table represents the maximum area per floor in square meters for each floor of a building of the indicated story height.

[a]See the accompanying text Special Requirements.

Key to Abbreviations

UA	Unlimited area	Spr	With sprinkler system throughout the building
UH	Unlimited height	Unspr	Without sprinkler system throughout the building
NP	Not permitted		

Combustible									
		Wood Light Frame							
Heavy Timber (page 390)		**1-Hour (page 391)**		**¾-Hour (page 391)**		**Unprotected (page 391)**			**CONSTRUCTION TYPE**
Spr	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**		
UA[a]	UA[a]	UA[a]	UA[a]	UA[a]	UA*	UA[a]	UA[a]	UH	**HEIGHT IN STORIES ABOVE GRADE AND MAXIMUM AREA PER FLOOR IN m²**
								6	
								5	
								4	
								3	
								2	
								1	

This table was compiled from information contained in the National Building Code of Canada 2015. It does not represent an official interpretation by the organization that issues this code.

OCCUPANCY B-1: DETENTION

Special Requirements

All Occupancy B-1 Detention buildings must be fully sprinklered.

Measurements

Height is measured as the number of stories at grade or above, excluding the roof. Area is measured as the greatest horizontal projection of the building above grade within the outside surfaces of exterior walls or the centerline of fire walls.

Further Information

For information on Occupancy classifications, see page 13. For information on mixed-use buildings, see page 377. For information on which code to consult, see pages 5 and 13.

Unit Conversions

$$1\,m^2 = 10.76\,sq\,ft$$

OCCUPANCY B-1: DETENTION

		Noncombustible							
CONSTRUCTION TYPE		**2-Hour (page 386)**		**1-Hour (page 387)**		**¾-Hour (page 387)**		**Unprotected (page 387)**	
		Spr	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**
HEIGHT IN STORIES ABOVE GRADE AND MAXIMUM AREA PER FLOOR IN m^2	UH	UA							
	6								
	5								
	4								
	3			8,000					
	2			12,000					
	1		NP	UA	NP	NP	NP	NP	NP

Each number in the table represents the maximum area per floor in square meters for each floor of a building of the indicated story height.

Key to Abbreviations

UA	Unlimited area	Spr	With sprinkler system throughout the building
UH	Unlimited height	Unspr	Without sprinkler system throughout the building
NP	Not permitted		

Combustible									
		Wood Light Frame							CONSTRUCTION TYPE
Heavy Timber (page 390)		1-Hour (page 391)		¾-Hour (page 391)		Unprotected (page 391)			
Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr		
								UH	HEIGHT IN STORIES ABOVE GRADE AND MAXIMUM AREA PER FLOOR IN m^2
								6	
								5	
								4	
								3	
								2	
NP	NP	NP	NP	NP	NP	NP	NP	1	

This table was compiled from information contained in the National Building Code of Canada 2015. It does not represent an official interpretation by the organization that issues this code.

OCCUPANCY B-2: MEDICAL TREATMENT

Special Requirements

All Occupancy B-2 Medical Treatment buildings must be fully sprinklered.

Measurements

Height is measured as the number of stories at grade or above, excluding the roof. Area is measured as the greatest horizontal projection of the building above grade within the outside surfaces of exterior walls or the centerline of fire walls.

Further Information

For information on Occupancy classifications, see page 13. For information on mixed-use buildings, see page 377. For information on which code to consult, see pages 5 and 13.

Unit Conversions

$$1\,m^2 = 10.76\,sq\,ft$$

OCCUPANCY B-2: MEDICAL TREATMENT

CONSTRUCTION TYPE		**Noncombustible**							
		2-Hour (page 386)		**1-Hour (page 387)**		**¾-Hour (page 387)**		**Unprotected (page 387)**	
		Spr	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**
HEIGHT IN STORIES ABOVE GRADE AND MAXIMUM AREA PER FLOOR IN m^2	UH	UA							
	6								
	5								
	4								
	3			8,000					
	2			12,000		1,600			
	1		NP	UA	NP	2,400	NP	500	NP

Each number in the table represents the maximum area per floor in square meters for each floor of a building of the indicated story height.

Key to Abbreviations

UA	Unlimited area	Spr	With sprinkler system throughout the building
UH	Unlimited height	Unspr	Without sprinkler system throughout the building
NP	Not permitted		

Combustible								CONSTRUCTION TYPE
		Wood Light Frame						
Heavy Timber (page 390)		1-Hour (page 391)		¾-Hour (page 391)		Unprotected (page 391)		
Spr	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**	**HEIGHT IN STORIES ABOVE GRADE AND MAXIMUM AREA PER FLOOR IN m²**
								UH
								6
								5
								4
								3
1,600		1,600		1,600				2
2,400	NP	2,400	NP	2,400	NP	500		1

This table was compiled from information contained in the National Building Code of Canada 2015. It does not represent an official interpretation by the organization that issues this code.

OCCUPANCY B-3: CARE

Special Requirements

All Occupancy B-3 Care buildings must be fully sprinklered.

In buildings not more than three stories in height:

- If housing not more than 10 occupants, NFPA 13R (residential) sprinkler systems are permitted.
- If containing not more than two care suites and not more than five occupants total, NFPA 13D (one- and two-family dwelling) sprinkler systems are permitted.

For more information on NFPA 13R and 13D sprinkler systems, see page 262. For other sprinkler and basement requirements, see page 380.

Measurements

Height is measured as the number of stories at grade or above, excluding the roof. Area is measured as the greatest horizontal projection of the building above grade within the outside surfaces of exterior walls or the centerline of fire walls.

Further Information

For information on Occupancy classifications, see page 13. For information on mixed-use buildings, see page 377. For information on which code to consult, see pages 5 and 13.

Unit Conversions

$$1\,m^2 = 10.76\,sq\,ft$$

OCCUPANCY B-3: CARE

CONSTRUCTION TYPE		Noncombustible							
		2-Hour (page 386)		1-Hour (page 387)		¾-Hour (page 387)		Unprotected (page 387)	
		Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr
HEIGHT IN STORIES ABOVE GRADE AND MAXIMUM AREA PER FLOOR IN m^2	UH	UA							
	6								
	5								
	4								
	3			8,000					
	2			12,000		1,600			
	1		NP	UA	NP	2,400	NP	600	NP

Each number in the table represents the maximum area per floor in square meters for each floor of a building of the indicated story height.

Key to Abbreviations

UA	Unlimited area	Spr	With sprinkler system throughout the building
UH	Unlimited height	Unspr	Without sprinkler system throughout the building
NP	Not permitted		

Combustible								CONSTRUCTION TYPE
Heavy Timber (page 390)		Wood Light Frame						
		1-Hour (page 391)		¾-Hour (page 391)		Unprotected (page 391)		
Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	HEIGHT IN STORIES ABOVE GRADE AND MAXIMUM AREA PER FLOOR IN m^2
								UH
								6
								5
								4
		1,800						3
1,600		2,700		1,600				2
2,400	NP	5,400	NP	2,400	NP	600	NP	1

This table was compiled from information contained in the National Building Code of Canada 2015. It does not represent an official interpretation by the organization that issues this code.

OCCUPANCY C: RESIDENTIAL

Special Requirements

For preliminary design purposes, assume individual dwelling units must be separated from other areas with 1-hour rated construction.

In buildings of Residential Occupancy throughout and not more than four stories in height, NFPA 13R (residential) sprinkler systems are permitted in lieu of NFPA 13 (commercial) systems. In buildings not more than three stories in height with not more than two dwelling units, NFPA 13D (one- and two-family dwelling) sprinkler systems are permitted. For more information on these sprinkler system types, see page 262.

Buildings of Combustible, 1-Hour, sprinklered Construction meeting the requirements in the table on these two facing pages may include Miscellaneous Assembly A-2 and Mercantile E Occupancies on the first- and second-floor levels, or Low-Hazard Industrial F-3 Occupancy vehicular parking on the first- through third-floor levels.

For more information about mass timber construction and Occupancy C buildings, see page 390.

For Residential Occupancy buildings not more than three stories in height and 600 m^2 (6458 sq ft) in area per floor, see Small Buildings, page 373.

For additional sprinkler and basement requirements, see page 380.

Excess Frontage

For unsprinklered buildings, the tabulated areas may be increased by 25% if the building faces at least two streets and by 50% if it faces at least three. In unsprinklered 1- or 2-Hour Noncombustible Construction, a building two stories in height and facing two or three streets may be of unlimited area.

Measurements

Height is measured as the number of stories at grade or above, excluding the roof. Area is measured as the greatest horizontal projection of the building above grade within the outside surfaces of exterior walls or the centerline of fire walls.

OCCUPANCY C: RESIDENTIAL

		Noncombustible							
CONSTRUCTION TYPE		**2-Hour (page 386)**		**1-Hour (page 387)**		**¾-Hour (page 387)**		**Unprotected (page 387)**	
		Spr	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**
HEIGHT IN STORIES ABOVE GRADE AND MAXIMUM AREA PER FLOOR IN m^2	UH	UA							
	6			6,000					
	5			7,200					
	4			9,000					
	3		4,000	12,000	4,000	1,800	600		
	2		6,000	UA	6,000	2,700	900		
	1		UA	UA	UA	5,400	1,800	NP	NP

Each number in the table represents the maximum area per floor in square meters for each floor of a building of the indicated story height.

[a]See the accompanying text Special Requirements.

Key to Abbreviations

UA	Unlimited area	Spr	With sprinkler system throughout the building
UH	Unlimited height	Unspr	Without sprinkler system throughout the building
NP	Not permitted		

Further Information

For information on Occupancy classifications, see page 13. For information on mixed-use buildings, see page 377. For information on which code to consult, see pages 5 and 13.

Unit Conversions

$$1\,\text{m}^2 = 10.76\,\text{sq ft}$$

CONSTRUCTION TYPE

HEIGHT IN STORIES ABOVE GRADE AND MAXIMUM AREA PER FLOOR IN m²

Combustible								
Heavy Timber (page 390)		**Wood Light Frame: 1-Hour (page 391)**		**Wood Light Frame: ¾-Hour (page 391)**		**Wood Light Frame: Unprotected (page 391)**		
Spr	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**	
								UH
		1,500						6
		1,800						5
		2,250						4
1,800	600	3,000[a]	800	1,800	600			3
2,700	900	4,500[a]	1,200	2,700	900			2
5,400	1,800	9,000[a]	2,400	5,400	1,800	NP	NP	1

This table was compiled from information contained in the National Building Code of Canada 2015. It does not represent an official interpretation by the organization that issues this code.

OCCUPANCY D: BUSINESS AND PERSONAL SERVICES

Special Requirements

Buildings of Combustible, 1-Hour, sprinklered Construction meeting the requirements in the table on these two facing pages may include Miscellaneous Assembly A-2, Mercantile E, or Medium- or Low-Hazard Industrial F-2 or F-3 Occupancies on the first- and second-floor levels, or Low-Hazard Industrial F-3 Occupancy vehicular parking on the first- through third-floor levels.

For more information about mass timber construction and Occupancy D buildings, see page 390.

For Business and Personal Services Occupancy buildings not more than three stories in height and 600 m^2 (6458 sq ft) in area per floor, see Small Buildings, page 373.

For additional sprinkler and basement requirements, see page 380.

Excess Frontage

For unsprinklered buildings, the tabulated areas may be increased by 25% if the building faces at least two streets and by 50% if it faces at least three. In unsprinklered 1- or 2-Hour Noncombustible Construction, a building two stories in height and facing two or three streets may be of unlimited area.

Measurements

Height is measured as the number of stories at grade or above, excluding the roof. Area is measured as the greatest horizontal projection of the building above grade within the outside surfaces of exterior walls or the centerline of fire walls.

Further Information

For information on Occupancy classifications, see page 13. For information on mixed-use buildings, see page 377. For information on which code to consult, see pages 5 and 13.

Unit Conversions

$$1\,m^2 = 10.76\,sq\,ft$$

OCCUPANCY D: BUSINESS AND PERSONAL SERVICES

CONSTRUCTION TYPE		**Noncombustible**							
		2-Hour (page 386)		**1-Hour (page 387)**		**¾-Hour (page 387)**		**Unprotected (page 387)**	
		Spr	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**
HEIGHT IN STORIES ABOVE GRADE AND MAXIMUM AREA PER FLOOR IN m^2	UH	UA							
	6		2,400	7,200	2,400				
	5		2,880	8,640	2,880				
	4		3,600	10,800	3,600				
	3		4,800	14,400	4,800	4,800	1,600	4,800	1,600
	2		7,200	UA	7,200	7,200	2,400	7,200	2,400
	1		UA	UA	UA	14,400	4,800	14,400	4,800

Each number in the table represents the maximum area per floor in square meters for each floor of a building of the indicated story height.

[a]See the accompanying text Special Requirements.

Key to Abbreviations

UA	Unlimited area	Spr	With sprinkler system throughout the building
UH	Unlimited height	Unspr	Without sprinkler system throughout the building
NP	Not permitted		

Combustible								CONSTRUCTION TYPE
		Wood Light Frame						
Heavy Timber (page 390)		1-Hour (page 391)		¾-Hour (page 391)		Unprotected (page 391)		
Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	HEIGHT IN STORIES ABOVE GRADE AND MAXIMUM AREA PER FLOOR IN m^2
								UH
		3,000						6
		3,600						5
		4,500						4
4,800	1,600	6,000[a]	1,600	4,800	1,600			3
7,200	2,400	9,000[a]	2,400	7,200	2,400			2
14,400	4,800	18,000[a]	4,800	14,400	4,800	NP	NP	1

This table was compiled from information contained in the National Building Code of Canada 2015. It does not represent an official interpretation by the organization that issues this code.

OCCUPANCY E: MERCANTILE

Special Requirements

See Special Requirements, page 466, for Mercantile E Occupancy within buildings conforming to the height and area limits of Residential C Occupancies, or page 468, for Mercantile E Occupancy within buildings conforming to the height and area limits of Business and Personal Services D Occupancies.

For Mercantile Occupancy buildings not more than three stories in height and 600 m^2 (6458 sq ft) in area per floor, see Small Buildings, page 373.

For additional sprinkler and basement requirements, see page 380.

Excess Frontage

For unsprinklered buildings, the tabulated areas may be increased by 25% if the building faces at least two streets and by 50% if it faces at least three.

Measurements

Height is measured as the number of stories at grade or above, excluding the roof. Area is measured as the greatest horizontal projection of the building above grade within the outside surfaces of exterior walls or the centerline of fire walls.

Further Information

For information on Occupancy classifications, see page 13. For information on mixed-use buildings, see page 377. For information on which code to consult, see pages 5 and 13.

Unit Conversions

$$1\,m^2 = 10.76\,sq\,ft$$

OCCUPANCY E: MERCANTILE

CONSTRUCTION TYPE		Noncombustible							
		2-Hour (page 386)		1-Hour (page 387)		¾-Hour (page 387)		Unprotected (page 387)	
		Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr
HEIGHT IN STORIES ABOVE GRADE AND MAXIMUM AREA PER FLOOR IN m^2	UH	UA							
	6								
	5								
	4			1,800					
	3		800	1,800	800	2,400	800		
	2		1,200	1,800	1,200	3,600	1,200		
	1		1,500	1,800	1,500	7,200	1,500	NP	NP

Each number in the table represents the maximum area per floor in square meters for each floor of a building of the indicated story height.

Key to Abbreviations

UA	Unlimited area	Spr	With sprinkler system throughout the building
UH	Unlimited height	Unspr	Without sprinkler system throughout the building
NP	Not permitted		

Combustible									
Heavy Timber (page 390)		Wood Light Frame: 1-Hour (page 391)		Wood Light Frame: ¾-Hour (page 391)		Wood Light Frame: Unprotected (page 391)			CONSTRUCTION TYPE
Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr		
								UH	HEIGHT IN STORIES ABOVE GRADE AND MAXIMUM AREA PER FLOOR IN m^2
								6	
								5	
		1,800						4	
2,400	800	1,800	800	2,400	800			3	
3,600	1,200	1,800	1,200	3,600	1,200			2	
7,200	1,500	1,800	1,500	7,200	1,500	NP	NP	1	

This table was compiled from information contained in the National Building Code of Canada 2015. It does not represent an official interpretation by the organization that issues this code.

OCCUPANCY F-1: INDUSTRIAL, HIGH-HAZARD

Special Requirements

Provincial or other local regulations may alter sprinkler requirements for buildings of this occupancy classification.

For additional sprinkler and basement requirements, see page 380.

Measurements

Height is measured as the number of stories at grade or above, excluding the roof. Area is measured as the greatest horizontal projection of the building above grade within the outside surfaces of exterior walls or the centerline of fire walls.

Further Information

For information on Occupancy classifications, see page 13. For information on mixed-use buildings, see page 377. For information on which code to consult, see pages 5 and 13.

Unit Conversions

$$1\,m^2 = 10.76\,sq\,ft$$

OCCUPANCY F-1: INDUSTRIAL, HIGH-HAZARD

CONSTRUCTION TYPE		Noncombustible							
		2-Hour (page 386)		1-Hour (page 387)		¾-Hour (page 387)		Unprotected (page 387)	
		Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr
HEIGHT IN STORIES ABOVEGRADE AND MAXIMUM AREA PER FLOOR IN m^2	UH								
	6								
	5								
	4	2,250							
	3	3,000		1,200		1,200			
	2	4,500		1,800		1,800		1,200	
	1	9,000	800	3,600	800	3,600	800	2,400	800

Each number in the table represents the maximum area per floor in square meters for each floor of a building of the indicated story height.

Key to Abbreviations

UA	Unlimited area	Spr	With sprinkler system throughout the building
UH	Unlimited height	Unspr	Without sprinkler system throughout the building
NP	Not permitted		

CONSTRUCTION TYPE

HEIGHT IN STORIES ABOVE GRADE AND MAXIMUM AREA PER FLOOR IN m^2

Combustible								
Heavy Timber (page 390)		Wood Light Frame: 1-Hour (page 391)		Wood Light Frame: ¾-Hour (page 391)		Wood Light Frame: Unprotected (page 391)		
Spr	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**	
								UH
								6
								5
								4
1,200								3
1,800		1,200		1,200				2
3,600	800	2,400	800	2,400	800	800	800	1

This table was compiled from information contained in the National Building Code of Canada 2015. It does not represent an official interpretation by the organization that issues this code.

OCCUPANCY F-2: INDUSTRIAL, MEDIUM-HAZARD

Special Requirements

See Special Requirements, page 468, for Medium-Hazard F-2 Occupancy within buildings conforming to the height and area limits of Business and Personal Services D Occupancies.

For Medium-Hazard Industrial Occupancy buildings not more than three stories in height and 600 m^2 (6458 sq ft) in area per floor, see Small Buildings, page 373.

For additional sprinkler and basement requirements, see page 380.

Excess Frontage

For buildings of Noncombustible, Unprotected, unsprinklered Construction, the tabulated areas may be increased by 25% if the building faces at least two streets and by 50% if it faces at least three. For all other unsprinklered buildings, the tabulated building area may be modified for three-story buildings only, such that when the building faces two streets, the building area may be 1340 m^2 (14,424 sq ft), and when it faces three streets, the building area may be 1500 m^2 (16,146 sq ft).

Measurements

Height is measured as the number of stories at grade or above, excluding the roof. Area is measured as the greatest horizontal projection of the building above grade within the outside surfaces of exterior walls or the centerline of fire walls.

Further Information

For information on Occupancy classifications, see page 13. For information on mixed-use buildings, see page 377. For information on which code to consult, see pages 5 and 13.

Unit Conversions

$$1\,m^2 = 10.76\,sq\,ft$$

OCCUPANCY F-2: INDUSTRIAL, MEDIUM-HAZARD

CONSTRUCTION TYPE	Noncombustible							
	2-Hour (page 386)		1-Hour (page 387)		¾-Hour (page 387)		Unprotected (page 387)	
HEIGHT IN STORIES ABOVE GRADE AND MAXIMUM AREA PER FLOOR IN m^2	Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr
UH	UA							
6								
5								
4			4,500		2,400			
3		1,070	6,000	1,070	3,200	1,070		
2		1,500	9,000	1,500	4,800	1,500	1,800	600
1		1,500	18,000	1,500	9,600	1,500	4,500	1,000

Each number in the table represents the maximum area per floor in square meters for each floor of a building of the indicated story height.

Key to Abbreviations

UA	Unlimited area	Spr	With sprinkler system throughout the building
UH	Unlimited height	Unspr	Without sprinkler system throughout the building
NP	Not permitted		

Combustible									CONSTRUCTION TYPE
		Wood Light Frame							
Heavy Timber (page 390)		1-Hour (page 391)		¾-Hour (page 391)		Unprotected (page 391)			
Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr		
								UH	HEIGHT IN STORIES ABOVE GRADE AND MAXIMUM AREA PER FLOOR IN m^2
								6	
								5	
2,400		2,400		2,400				4	
3,200	1,070	3,200	1,070	3,200	1,070			3	
4,800	1,500	4,800	1,500	4,800	1,500			2	
9,600	1,500	9,600	1,500	9,600	1,500	NP	NP	1	

This table was compiled from information contained in the National Building Code of Canada 2015. It does not represent an official interpretation by the organization that issues this code.

OCCUPANCY F-3: INDUSTRIAL, LOW-HAZARD

Special Requirements

A single-story unsprinklered building of any Construction Type may be of unlimited area when it is used solely for low-fire-hazard activities, such as power generation or the manufacture and storage of noncombustible materials.

See Special Requirements, page 466, for Low-Hazard Industrial F-3 Occupancy within buildings conforming to the height and area limits of Residential C Occupancies, or page 468, for Low-Hazard Industrial F-3 Occupancy within buildings conforming to the height and area limits of Business and Personal Services D Occupancies.

For Low-Hazard Industrial Occupancy buildings not more than three stories in height and 600 m^2 (6458 sq ft) in area per floor, see Small Buildings, page 373.

For additional sprinkler and basement requirements, see page 380.

Vehicle Parking Garages

For enclosed parking garages, which rely on mechanical ventilation to prevent the accumulation of exhaust gases, and for naturally ventilated open parking garages with other occupancies above, use the height and area tables on these two facing pages. For open parking garages without other occupancy above, use either the tables on these two facing pages or those on pages 478–479 for Occupancy F-3: Open-Air Garages.

The minimum clear height within parking garage tiers is 2 m (6′-7″). Every story of a below-grade garage must be sprinklered, except where the story is open-air. For more information on the design of parking facilities, see Designing for Parking, beginning on page 337.

For wall opening and building separation distance requirements for open parking garages, see page 351. For special height and area provisions for mixed-use, below-grade parking with other occupancies above, see page 377. For parking garages serving single dwelling units in small buildings, see page 373.

OCCUPANCY F-3: INDUSTRIAL, LOW-HAZARD

		Noncombustible							
CONSTRUCTION TYPE		**2-Hour (page 386)**		**1-Hour (page 387)**		**¾-Hour (page 387)**		**Unprotected (page 387)**	
		Spr	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**
HEIGHT IN STORIES ABOVE GRADE AND MAXIMUM AREA PER FLOOR IN m^2	UH	UA							
	6		2,400	7,200	2,400				
	5		2,880	8,640	2,880				
	4		3,600	10,800	3,600	3,600	1,200	3,600	1,200
	3		4,800	14,400	4,800	4,800	1,600	4,800	1,600
	2		7,200	21,600	7,200	7,200	2,400	7,200	2,400
	1		UA	UA	UA	16,800	5600[a]	16,800	5600[a]

Each number in the table represents the maximum area per floor in square meters for each floor of a building of the indicated story height.

[a]See the accompanying text Special Requirements.

Key to Abbreviations

UA	Unlimited area	Spr	With sprinkler system throughout the building
UH	Unlimited height	Unspr	Without sprinkler system throughout the building
NP	Not permitted		

Excess Frontage

For unsprinklered buildings, the tabulated areas may be increased by 25% if the building faces at least two streets and by 50% if it faces at least three.

Measurements

Area is measured as the greatest horizontal projection of the building above grade within the outside surfaces of exterior walls or the centerline of fire walls.

Further Information

For information on Occupancy classifications, see page 13. For information on mixed-use buildings, see page 377. For information on which code to consult, see pages 5 and 13.

Unit Conversions

$$1\,m^2 = 10.76\,sq\,ft$$

Combustible								CONSTRUCTION TYPE
		Wood Light Frame						
Heavy Timber (page 390)		1-Hour (page 391)		¾-Hour (page 391)		Unprotected (page 391)		
Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr	HEIGHT IN STORIES ABOVE GRADE AND MAXIMUM AREA PER FLOOR IN m^2
								UH
								6
								5
3,600	1,200	3,600	1,200	3,600	1,200			4
4,800	1,600	4,800	1,600	4,800	1,600			3
7,200	2,400	7,200	2,400	7,200	2,400			2
16,800	5600[a]	14,400	5600[a]	14,400	5600[a]	NP	NP	1

This table was compiled from information contained in the National Building Code of Canada 2015. It does not represent an official interpretation by the organization that issues this code.

OCCUPANCY F-3: OPEN-AIR GARAGES

Special Requirements

Garages, as shown in the following table:

- May not be more than 22 m (72 ft) high, measured from grade to the underside of the top-level ceiling
- May have no other occupancy above
- May have no point on any floor more than 60 m (197 ft) from an exterior wall opening.
- For garages not meeting these criteria, see the height and area requirements for Occupancy F-3, Industrial, Low Hazard, pages 476–477.

For wall opening and building separation distance requirements for open parking garages, see page 351.

The minimum vertical clear height within parking garage tiers is 2 m (6′-7″). For more information on the design of parking facilities, see Designing for Parking, beginning on page 337.

Measurements

Height is measured from grade to the underside of the top-level ceiling. Area is measured as the greatest horizontal projection of the building above grade within the outside surfaces of exterior walls or the centerline of fire walls.

Further Information

For information on Occupancy classifications, see page 13. For information on mixed-use buildings, see page 377. For information on which code to consult, see pages 5 and 13.

Unit Conversions

$$1\,m^2 = 10.76\,sq\,ft$$

OCCUPANCY F-3: OPEN-AIR GARAGES

		Noncombustible							
CONSTRUCTION TYPE		**2-Hour (page 386)**		**1-Hour (page 387)**		**¾-Hour (page 387)**		**Unprotected (page 387)**	
		Spr	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**	**Spr**	**Unspr**
HEIGHT *IN METERS* ABOVE GRADE AND MAXIMUM AREA PER FLOOR IN m²	22 m	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000

Each number in the table represents the maximum area per floor in square meters for each floor of a building of the indicated story height.

Key to Abbreviations

UA	Unlimited area	Spr	With sprinkler system throughout the building
UH	Unlimited height	Unspr	Without sprinkler system throughout the building
NP	Not permitted		

Combustible							
		Wood Light Frame					
Heavy Timber (page 390)		1-Hour (page 391)		¾-Hour (page 391)		Unprotected (page 391)	
Spr	Unspr	Spr	Unspr	Spr	Unspr	Spr	Unspr
NP	NP	NP	NP	NP	NP	NP	NP

This table was compiled from information contained in the National Building Code of Canada 2015. It does not represent an official interpretation by the organization that issues this code.

CONSTRUCTION TYPE

22 m

HEIGHT IN METERS ABOVE GRADE AND MAXIMUM AREA PER FLOOR IN m^2

APPENDIX A
EXAMPLE USE OF THIS BOOK

The following example illustrates the use of this book to complete the preliminary design of a building's technical systems. For a more brief explanation of approaches to using this text, see How to Use This Book, page xi.

THE PROBLEM

You are beginning the design of a suburban office building on a large site in the Midwestern United States. Preliminary design assumptions are:

- A three-story structure
- Building area of 86,000 sq ft per floor
- Structural column bays approximately 30 × 34 ft
- A floor-to-ceiling height of about 9′-6″
- A fully sprinklered building

BUILDING CODE AND OCCUPANCY

We refer first to Designing with Building Codes. On page 5, we determine that our building should be designed to the requirements of the International Building Code. Referring to the Index of Occupancies on page 5, we see that Business Offices are classified as Occupancy B. To learn more about this Occupancy B, Business, we also review its description on page 6 and verify that this is the appropriate choice for our project.

BUILDING HEIGHT AND AREA LIMITS

Next, we refer to the introductory material on building code height and area limitations beginning on page 372. Reading from the table on that page, we note that requirements for International Building Code Occupancy B buildings can be found on pages 406–407. Turning to these pages, we see that the area figures provided in the table are for all floors of a building. The total area of our proposed building is 258,000 sq ft (86,000 sq ft per floor × 3 floors). Reading from the table, we see that we can use any variety of Type I Construction, sprinklered Type II-A 1-Hour Construction (allowing an area of all floors of 337,500 sf), or any sprinklered Type IV Mass Timber and Heavy Timber Construction (allowing 324,000 sq ft or more depending on the Type). We also notice that if we reduce the area of our building to no more than 256,500 sq ft, we can use sprinklered Type III-A 1-Hour Ordinary Construction as well.

CONSTRUCTION TYPE

We eliminate sprinklered Types I-A and I-B construction as unnecessarily expensive in comparison to sprinklered Type II-A construction. We also eliminate the unsprinklered Type I construction types, as the owner's building insurance offers significant financial incentives to build with fire sprinklers. Considering Types III and IV Construction, we follow the page references for these construction types in the height and area table and learn that these are various hybrid wood and noncombustible systems. Since we prefer to build without wood in this instance, we turn our attention to Type II-A Construction, page 386, and determine that we can use any of the following construction methods:

- Structural steel with 1 hour of fire protection
- Sitecast concrete or precast concrete, with minimum sizes of components as noted in the text
- Lightweight steel framing
- Masonry

SELECTING A STRUCTURAL SYSTEM

We turn to pages 24–29 for advice on selecting a structural system. Some factors that we know are important for this project include: minimizing the area occupied by columns or bearing walls, permitting construction under adverse weather conditions, and minimizing on-site erection time. At this point, steel frame construction begins to appear to be a good choice for our building.

Turning to page 31, we confirm that steel column and beam framing can readily span the 30 × 34-ft dimensions required for our planned structural bay, and on pages 32–33 we see that it has the necessary capacity for office building loads. On page 35 we note the generally favorable global warming potential of structural steel. Information on pages 36–37 confirms that steel frame construction is a common choice for office building construction. With all this information in hand, and knowing that steel construction is an economical system in the location where we are building, we decide to proceed with a structural steel structural system.

CONFIGURING THE STRUCTURAL SYSTEM

Reviewing pages 41–49, we determine that our structure should be a column and beam system. Economical options for achieving lateral stability include a shear wall, a braced frame, or a system using semirigid joints in combination with one of the former choices. With these options, we are satisfied that we will be able to include the necessary elements to achieve lateral stability in our structure without difficulty.

SIZING THE STRUCTURAL SYSTEM

Columns

The page references at the top of the chart on pages 28–29 direct us to pages 98–106 for information on sizing steel structures. After reviewing the introductory information on page 93, we turn to pages 98–99 for the sizing of structural steel columns. A ground floor column is the most critical, as it supports a total tributary area of two floors plus one roof times the size of a column bay, or 3060 sq ft (3 levels × 30 ft × 34 ft).

The normal-height column chart on page 99 indicates that a W8 or W10 column is required. Noting on page 32 that office building structures are subjected to light to medium live loads, we will assume a W8 column for preliminary design purposes and note its dimensions as 8 by 8 in. On upper floors, we will assume that a lighter-weight version of the W8 shape is used. Maintaining the same nominal size will simplify connections between column sections. (Alternatively, our fabricator and erector may opt to use a single piece, three stories high, for each column.)

Decking

Next, we turn to pages 102–103 for steel floor and roof decking, and determine that decking spans in the range of 6 to 15 ft are most practical. We will return to these pages to determine the final floor slab thickness after we investigate further the framing of beams and girders.

Bay Framing and Floor Slab

Turning to page 104, we look at a beam and girder framing diagram and note the recommendation to span girders the short direction of the structural bay, or, in our case, in the 30-ft direction. For beam spacing, we consider placing beams at third points along the girder, resulting in a beam spacing of 10 ft. Returning to page 103, we see that this requires us to use 2-in. metal decking with a total slab depth of 4½ to 5 in., including the concrete topping. Reading from the lower chart on the same page, we choose 2-in.-deep roof decking.

Alternatively, we could consider placing beams at girder quarter points, resulting in a beam spacing of 7½ ft. In this case, returning to page 103, we see that we can use 1½ in. metal decking with a total slab depth of about 4 in. Later in the design process, we will ask our structural engineer to consider the economics of both of these options.

Sizing of Beams and Girders

Next, we turn to pages 104–105 for the sizing of beams and girders. Reading from the chart, we see that beams spanning 34 ft will need to be 18 or 21 in. deep. Alternatively, with composite construction, this depth could perhaps be reduced to about 16 in. We decide on an 18-in.-deep beam. Girders spanning 30 ft need to be 18 to 21 in. deep. We will use a lighter-weight, deeper 21-in. section to facilitate the connection with the 18-in.-deep beams.

TO SUMMARIZE

- Structural bay: 30 × 34 ft
- Girders: 21-in. deep, span 30 ft
- Beams: 18 in. deep, span 34 ft, spacing 10 ft
- Decking: 2 in. deep, 5-in.-deep total floor slab
- Columns: 8 × 8 in.

DAYLIGHTING

We wish to investigate how the use of daylighting may affect the shape of our building. On page 145, we determine that our site is open and does not have any significant obstructions to daylight. On page 147, we note that an elongated plan that puts work areas within approximately 30 ft of windows is recommended. This is further explained on page 148. Considering our building, if it were two bays at 30 ft wide each, or 60 ft wide total, it would be 1400 ft long, over a quarter of a mile. Alternatively, we could build to four or five stories, or we could arrange the plan of the building with many branches, as illustrated in the plan diagrams.

On a more detailed level, we note that light shelves could help to control light distribution (page 153), and that we should try to keep window heads as high as possible (page 148). On the uppermost floor, toplighting may be a good option to consider.

In conclusion, we will explore building designs as long and slender as practical in order to place the largest number of workers within daylit distance of outside walls. We will also keep window heads as high as possible. After the building design has progressed further and basic floor plans and sections have been prepared, we will return to this section to carry the daylighting design further.

MECHANICAL AND ELECTRICAL EQUIPMENT

HVAC Systems

We turn to page 163 to begin the design of our mechanical and electrical systems. Common choices of HVAC systems are given on pages 166–167. For office buildings, VAV, active chilled beams, hydronic convectors (for heating only) and hydronic radiant heating and cooling are listed as frequently used options. We also turn to pages 168–173. Noting maintaining flexibility for future space reconfigurations, we settle on an all-air VAV system.

We turn to pages 223–227 to read about passive heating and cooling systems. Based on the climate conditions in our project location and our decision to adopt a relatively slender, elongated building form, we decide that it might be possible to provide natural ventilation cooling to building occupants during the off-peak spring and fall seasons. We make a note to bring this idea to our first meeting with our mechanical engineer, where it can be explored in greater detail.

Returning to the design of our primary heating and cooling system, we go to pages 174–175, which describe a VAV system and its variants and list the major components of the system for which we must find space. VAV box dimensions are given here, but the sizes of the rest of the components will be found elsewhere in this section.

Can we use a packaged system? Suppose that we want to restrict duct runs to 120 ft for economy of operation. This means that each fan room or packaged unit can service an area 240 ft long (ducts run in two opposite directions). For a building 1400 ft long, we would need six zones, each with its own fan room or packaged unit. Each zone would contain 43,000 sq ft on three floors (258,000 sq ft/six zones). Consulting the sizing chart on page 216, to which we are referred by the note on page 175, we discover that, although we could use single-packaged units, they would be very large. We decide instead to proceed with a fan room solution.

We turn to the chart on page 218 to determine the sizes of major components of an air-handling system relying on fan rooms. We assume one fan room per zone, serving all three floors in that zone. We read from this chart that for a floor area of 43,000 sq ft, a little over 60,000 cfm of air is required for cooling. Main supply and return ducts will total about 38 sq ft each. If on each floor two main supply ducts are used, each duct will have to be about 6.3 sq ft (38 sq ft/three floors/two ducts per floor) in area. At a depth of 18 in., each duct will be about 51 in. wide. Branch ducts will total about 62 sq ft in area for all three floors.

Reading further down on the same chart, each fan room will occupy about 1800 sq ft of floor area, and will need about 180 sq ft of fresh air louver and about 130 sq ft of exhaust air louver. To minimize the ductwork for these items, we will try to locate fan rooms as close as possible to outside wall locations. Pages 191–192 give additional information on fan rooms and ductwork arrangements.

Returning to the chart on page 216, we determine that each zone requires 125 tons of cooling and a mechanical room for the boiler and chiller 900 sq ft in area. On page 186 is a more detailed description of this facility. Note the need for a chimney. In addition, 175 sq ft of the roof will be occupied by a cooling tower, as shown and described on page 187.

PLENUM SPACE AND FLOOR-TO-FLOOR HEIGHT

Assuming that most horizontal distribution of services will be above the ceiling, we need to determine the depth of the plenum. Page 214 tells us that we need 20 in. of plenum height beneath the girders. We have previously determined that the girders will be 21 in. deep and the floor slab and decking 5 in. deep, for a total of 26 in. Adding the depths of structure and plenum, we arrive at a total depth of 46 in., or 3′-10″.

A ceiling height of about 9′-6″ is desired. Adding the 3′-10″ plenum to this, we arrive at a floor-to-floor height of about 13′-4″.

BUILDING EGRESS AND CIRCULATION

We go to pages 269–285 for general definitions and advice on egress layout.

Occupant Load

To size the egress components, we need to know the occupant load of the building. This is found using page 305. For a business use, an occupant load of 150 sq ft per occupant is specified. Thus, the egress system on each floor must be designed to accommodate 574 occupants (86,000 sq ft per floor/150 sq ft per occupant).

Egress System

On page 277, we find that we must provide a minimum of three exits from each floor. If the building is 1400 ft long, three exits will give a maximum travel distance of 350 ft. On page 306, we see that the maximum distance to the nearest exit is 300 ft in a sprinklered Business Occupancy building. Therefore, we must provide at least four exits.

With four exits, the occupant load per exit is 144 (860 occupants per floor/four exits per floor). Referring to page 308, we see that we must provide 0.15 in. of width per occupant for doors, corridors, and ramps and 0.2 in. per occupant for stairs. We can either work this out arithmetically or use the chart on page 309. For example, for exit stairs, the required width based on the number of occupants is 29 in. (144 occupants × 0.2 in. per occupant). But page 307 tells us that the stair may not be less than 44 in. when serving more than 50 occupants. We will use 44-in. stairs.

Exit Stairway Design

Now we can determine how big each stair tower is. We go to the Two-Flight Exit Stairway Design table on page 324. Earlier, we calculated our floor-to-floor height to be 11′-4″. The table tells us that we will have 20 risers at 6.80 in., with treads at 11 in. The inside length of the stairway will be 15′-7″. The width will be twice 44 in. plus a center space or wall if we wish it; we assume a 6-in. center wall to arrive at a width of 94 in., or 7′-10″. If we assume 8-in. walls around the stair, the outside dimensions of the stairway will be 16′-11″ by 9′-2″.

Elevators

Page 207 tells us that we need one elevator for every 50,000 sq ft and 2 to 2½ floors served. Our building has 258,000 sq ft of floor area and three floors, but the ground floor does not need to be considered as a served floor. So we have 172,000 sq ft (2/3 × 258,000 sq ft) and two floors served. Dividing 172,000 sq ft by 50,000 sq ft yields 3.4, which we round up to four elevators required. We may want to distribute these in banks of two elevators each to minimize waiting times.

If we use 3000-lb elevators, we see from the table on the same page that each shaft must have at least 8′-4″ by 7′-5″ inside clear dimensions. If we add to this shaft walls 4 in. thick, the overall shaft dimensions are 9′-0″ by 8′-1″.

Given the low building height, we see that either hydraulic or machine room-less types are suitable. We make a note to investigate to these two options in more detail at a later date.

Accessible Routes

Information on accessibility is provided on pages 286–290. We note that accessibility requirements do apply to our building and that at least 60% of its entrances must be accessible. Accessible egress will be provided by elevators and stairways. As our design develops, we will also be sure to meet the requirements for minimum widths of accessible routes, latchside door clearances, and so on.

ANCILLARY SPACES

Transformers and Switchgear Rooms

We will need one or more large transformers to reduce utility high transmission voltages to lower voltages for use in our building. Pages 188–189 indicate that these may be either mounted on concrete pads at ground level or placed in transformer vaults underground. The sizes required for underground vaults are large, and we realize that pad mounting will be more economical. The largest floor area listed per transformer pad is 180,000 sq ft, which can serve more than half of the floor area of our building. We will look for good locations for at least two transformer pads just outside the walls of the building.

The diagrams on page 189 indicate that each pad will require a switchgear room. If we use two transformers and switchgear rooms, each will serve 129,000 sq ft. The accompanying table shows that a 100,000-sq-ft building needs a room 30 by 20 ft in plan dimension by 11 ft tall. We may need a room somewhat larger than this, say 30 by 30 ft. As noted in the text on this page, each switchgear room should be on an outside wall to facilitate ventilation.

Electrical and Telecommunications Rooms

Electrical rooms are described on page 199; no point on any floor should be more than 100 to 125 ft from a room with internal dimensions of approximately 8 × 10 ft. Additionally, telecommunication rooms, with internal dimensions of 10 × 12 ft, should be located such that all points on a floor are within 300 ft. Both types of rooms should be aligned above one another on the three floors. As we begin to develop the floor plans, we will keep these requirements in mind. Given the rapid changes in telecommunications services, we also make a note to review these assumptions at an early date with technical personnel familiar with the industry.

Toilets

Toilet facilities may be sized and planned with the aid of the charts on pages 202–203.

PARKING

If provision for parking is required, information on the preliminary design of parking facilities can be found beginning on page 337.

WHERE THIS BRINGS US

In an hour or two, with this book as our consultant, we have made preliminary decisions in every technical area that impacts the configuration of the building we are about to design:

- We have selected a structural system and assigned approximate sizes to its members.
- We are aware of the requirements for daylighting the building.
- We have made a tentative choice of an HVAC system and know the sizes and locations of its major components.
- We know the requirements for egress from the building, including the sizes of the stair enclosures.
- We know the number and size of elevators and have determined requirements for accessibility.
- We have determined the floor-to-floor height and the depth of the ceiling plenum space.
- We know the required components of the electrical and telecommunications systems, their locations, and their sizes.
- We have sized the toilet facilities and, if needed, allocated space for parking.

Thus, we are ready to launch the process of finding a good form for the building, knowing that we will make adequate provisions for all its major systems.

APPENDIX B
UNITS OF CONVERSION

Inch-Pound (U.S. Customary Units)	METRIC (SI)
1 in.	25.40 mm
1 ft	304.8 mm
1 ft	0.3048 m
1 lb	0.4536 kg
1 ft^2	0.0929 m^2
1 ft^3	0.02832 m^3
1 psi	6.895 kPa
1 lb/ft^2	47.88 Pa
1 lb/ft^3	16.02 kg/m^3
1 ft/sec	0.3048 m/sec
1 ft/min	0.00508 m/sec
1 cfm	0.4719 l/sec
1 cfm	1.699 m^3/hr
1 BTU	1.055 kJ
1 BTU	0.2521 kcal
1 BTU/h (BTUH)	0.2931 W
1 ton (refrigeration)	3.517 kW

METRIC (SI)	Inch-Pound (U.S. Customary Units)
1 mm	0.03937 in.
1 m	39.37 in.
1 m	3.281 ft
1 kg	2.205 lb
1 m^2	10.76 ft^2
1 m^3	35.31 ft^3
1 kPa	0.1450 psi
1 Pa	0.02089 lb/ft^2
1kg/m^3	0.6243 lb/ft^3
1 m/sec	3.281ft/sec
1 m/sec	196.9 ft/min
1 l/sec	2.119 cfm
1 m^3/hr	0.5886 cfm
1 kJ	0.9479 BTU
1 kcal	3.966 BTU
1 W	3.412 BTU/h (BTUH)
1 kW	0.2843 ton (refrigeration)

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